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Residential Wood Combustion Study Task 2A. Current and Projected Air Quality Impacts

Green (Del) Associates, Inc., Woodburn, OR

Prepared for

Environmental Protection Agency, Seattle, WA

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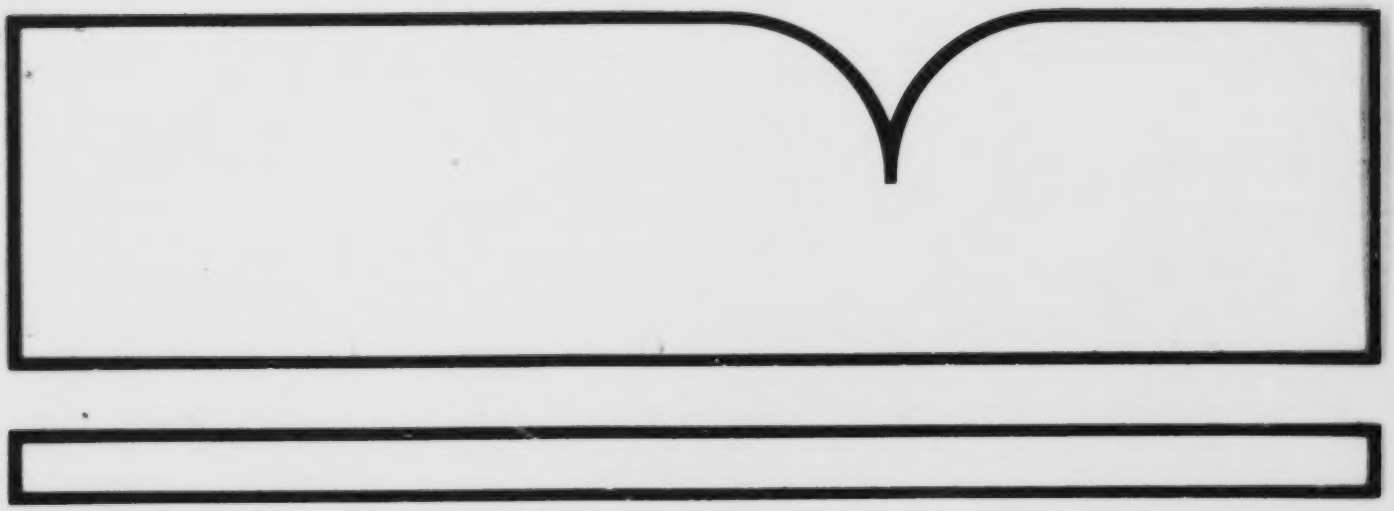

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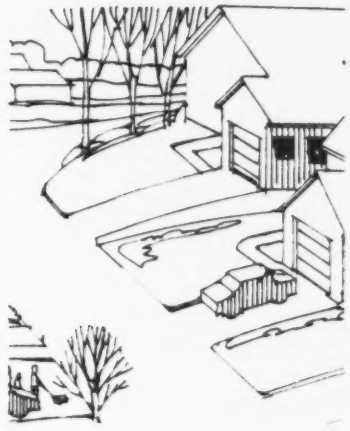
Residential Wood Combustion Study

Task 2A
Current and Projected Air Quality Impacts



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This report focuses on the issues of future particulate air quality impact from residential wood combustion (RWC) sources in the Pacific Northwest, the basis for the projections, air resource implications and potential mitigating measures. The intent of this task is to draw together the findings from other portions of the Residential Wood Combustion Study: Task 1 (Ambient Air Quality Impact Analysis), Task 2B (Household Information Sruvey), and Task 3 (Wood Fuel Use Projections) (Report Nos. EPA 910/9-82-089a, EPA 910/9-82-089d, and EPA 910/9-83-089e). Results developed from Task 6 (Control Strategy Alternatives) and Task 5 (Wood Stove Emission Studies) are discussed within the framework of potential mitigating measures (Report Nos. EPA 910/9-82-089i and EPA 910/9-82-089g). Current RWC particulate impacts identified as a part of this study, as well as those quantified by other Pacific Northwest aerosol studies, are presented as are air quality projection methodology and impact projection implications.

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RESIDENTIAL WOOD COMBUSTION STUDY

TASK 2A

Current and Projected Air Quality Impacts

RESIDENTIAL WOOD COMBUSTION STUDY

TASK 2A

Current and Projected Air Quality Impacts

-Final Report-

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U.S. ENVIRONMENTAL PROTECTION AGENCY
Region X
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Task Manager

Wayne Grotheer

January, 1983

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THEY ARE LISTED BELOW FOR YOUR CONVENIENCE.

EPA 910/9-82-089a	Residential Wood Combustion Study Task 1 - Ambient Air Quality Impact Analysis
EPA 910/9-82-089b	Task 1 - Appendices
EPA 910/9-82-089c	Task 2A - Current & Projected Air Quality Impacts
EPA 910/9-82-089d	Task 2B - Household Information Survey
EPA 910/9-82-089e	Task 3 - Wood Fuel Use Projection
EPA 910/9-82-089f	Task 4 - Technical Analysis of Wood Stoves
EPA 910/9-82-089g	Task 5 - Emissions Testing of Wood Stoves Volumes 1 & 2
EPA 910/9-82-089h	Task 5 - Emissions Testing of Wood Stoves Volumes 3 & 4 (Appendices)
EPA 910/9-82-089i	Task 6 - Control Strategy Analysis
EPA 910/9-82-089j	Task 7 - Indoor Air Quality

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TABLE OF CONTENTS

	page
Acknowledgements	iv
List of Tables	v
List of Figures	vi
1.0 Introduction	1
2.0 Current Residential Wood Combustion Air Quality Impacts	1
2.1 Portland and Medford Aerosol Characterization Studies	2
2.2 Missoula, Montana Studies	3
2.3 Task 1 Findings	7
2.4 Trends in RWC Particulate Impacts	10
3.0 Projections of Future RWC Impacts	10
3.1 Wood Fuel and Emission Projections	10
3.2 Wood Use - Air Quality Relationships	13
3.3 Impact Projections (1981-2000)	15
4.0 Discussion of Projection Results	17
4.1 Implications for Future Air Quality	17
4.2 Potential Mitigating Measures	21
5.0 Summary and Conclusions	22
6.0 References	24
Appendix 1 - Glossary	

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LIST OF TABLES

TABLE		PAGE
1	Residential Wood Combustion Impacts In The Pacific Northwest (Historical Studies).	4
2	CMB Estimates of RWC Impacts (October 1980 - March, 1981) Task 1.	8
3	Summary of Short Term Trends in Wood Fuel Use.	11
4	Projections for Residential Wood Fuel Use and Corresponding Particulate Emissions.	12
5	Wood Fuel Use - Household Survey Results for February, 1981.	14
6	Estimated Future RWC Impacts (24-hour Reasonable Worst Case)	16

LIST OF FIGURES

FIGURE		PAGE
1	Source Contributions to Air Particles in Downtown Portland.	5
2	Annual Average Source Contributions for MACS Sampling Period.	6
3	Source Contributions to Fine Particle Fraction (Oct. 1980 - March, 1981) Task 1.	9
4	RWC Impact Projections (1981-2000).	18
5	B_{scat} - Fine Aerosol Mass Relationship - Portland, Oregon.	20

1.0 INTRODUCTION

The use of wood as a residential space heating fuel has increased significantly in the Pacific Northwest in recent years (171, 172, 315). Information on trends in wood stove sales, commercial firewood distribution, emission inventory and ambient air quality monitoring data collectively point toward a growing concern as to the current, and future, impact of residential wood combustion (RWC) on community air quality and public health. The problem of residential solid fuel-related air pollution dated back to London in the year 1250 (82-87, 212). More recent studies of the potential public health effects of RWC emissions, however, have underscored the range of carcinogenic and potentially toxic pollutants associated with wood combustion emissions - most of which are within the size range of particles deposited within the bronchial tract and lungs (1,2,29-34,42,43,80,95,97,98,101,122,144, 145,151,182,194,197,200,202,208,209,214,218,232,234,242,248,276,288,290, 318,330,334,338).

In addition to concerns surrounding potential public health effects associated with ambient and indoor exposure to RWC emissions, regulatory agencies are becoming increasingly concerned about visibility reduction and airshed capacity issues related to wood smoke (74,94,105,147,157-159, 244,306,312,320,322). Recent data developed for the Portland, Oregon metropolitan area, for example, shows that the annual emissions from RWC sources now exceed those from industrial point sources. If industrial source emissions are to expand with the economic growth of Pacific Northwest communities, RWC emissions and potential emission growth must be addressed.

This document (Task 2A) focuses on the issues of future particulate air quality impact from RWC sources, the basis for the projections, air resource implications and potential mitigating measures. The intent of this task is to draw together the findings from Task 1 (Current RWC Air Quality Impacts), Tasks 2B (Current Wood Useage), and Task 3 (Wood Fuel Use Projections). Results developed from Task 6 (Control Strategy Alternatives) and Task 5 (Wood Stove Emission Studies) are discussed within the framework of potential mitigating measures. Current RWC particulate impacts identified as a part of this study, as well as those quantified by other Pacific Northwest aerosol studies, are presented as are air quality projection methodology and impact projection implications.

2.0 CURRENT RESIDENTIAL WOOD COMBUSTION AIR QUALITY IMPACTS

Development of projections for future RWC impacts first requires an understanding of the relationships between current air quality impacts and emission strength. Although numerous investigators have reported studies, only four studies conducted within the Pacific Northwest have explored this relationship (29-34,42,43,80,95,97,98,101,122,144,145,151, 182,194,197,200,202,208,209,214,218,232,234,242,248,276,288,290,318,330, 334,338). Several other, less definitive studies have been conducted in Bend and Eugene, Oregon. Although a brief review of the findings from each of these studies is presented to provide a basis upon which future impact projections can be based, direct comparison of impacts between studies is confounded by differences in study experimental design and the meteorological conditions under which the samples were taken.

In interpreting the results from these studies, it is important to distinguish between the numerous sources which potentially contribute to the impacts discussed in this document. Much of the evidence developed to date implicating residential wood combustion sources within the Northwest have been developed through source apportionment studies founded on chemical mass balance, carbon-14 analysis, temporal variations in light scattering measurements (both seasonal and diurnal), carbon thermograph analysis and dispersion modeling. Each approach is briefly described in Appendix 1.

These techniques have been used both jointly and independently to assess impacts associated with fireplace and wood stove emissions from residential dwellings (9). With the exception of dispersion modeling analysis (which is based on emission factors adjusted to agree with CMB and ^{14}C results), all of the impact assessment methods employed quantify impacts associated with vegetative burning, a general source class that includes (a) fireplace, (b) wood stove emissions, (c) slash burning, (d) forest fires, (e) structural fires, (f) backyard burning of yard debris, (g) grass and field burning and (h) burning associated with land clearing. Further apportionment of vegetative burning emissions to isolate emissions from urban residential space heating sources has been based on (1) quantification of vegetative burning components transported into the urban environment (sources c, d, g and h) and (2) known seasonal variations in backyard burning activity. Emissions associated with accidental structural fires have been assumed to be insignificant in relation to RWC emissions. Unburned vegetative materials such as pollen, spores, wood fibers and leaf fragments have been excluded as possible contributing sources on the basis of particle size.

Perhaps the strongest evidence supporting the premise that RWC sources are the predominant contributor to the urban vegetative burning component is (a) the level of agreement between the CMB and carbon-14 results, (b) the seasonal variability in RWC impacts follows known trends in wood burning emissions and space heating demand and (c) spatial variability patterns in RWC estimated impacts are reasonable with respect to wood burning emission density patterns in urban areas. For example, RWC impacts are consistently found to be highest in residential land use areas than in commercial or industrial areas. The weight of evidence, then, supports the position that the urban vegetative burning component is dominated by residential wood combustion emissions. Since the focus of this document is primarily centered on the identification and projection of worst case 24 hour impacts within urban areas during the winter months when RWC emissions are maximized, air quality impacts identified as vegetative burning have been considered as of residential wood combustion origin.

2.1 Portland and Medford Aerosol Characterization Studies

Studies conducted by the State of Oregon Department of Environmental Quality have quantified the impact of residential wood combustion in the Portland and Medford Air Quality Maintenance Areas. Conducted during the periods June, 1977 to April, 1978 and April 1979 to March, 1980, respectively, the Portland Aerosol Characterization Study (PACS) and Medford Aerosol Characterization Study (MACS) used chemical mass balance (CMB) and radiocarbon ($^{12}C/^{14}C$) source apportionment techniques to quantify residential wood

combustion impacts to fine ($\leq$ 2.5 μm) and total particulate fractions. Impact estimates representing both annual average and 24 hour periods were developed. Results from these programs are listed in Table 1. Figures 1 and 2 illustrate the magnitude of the impacts associated with RWC emissions and other sources to annual average total and respirable particulate mass in Portland and Medford. The major sources of respirable particles in Portland, on an annual basis, were found to be residential wood burning (20%), motor vehicle exhaust (15%) and secondary aerosols (14%). Within the Medford airshed, 47% of the locally generated respirable particulate mass has been assigned to residential wood combustion, 17% to industrial sources and 5% to transportation. In terms of 24 hour worst case episodes, residential wood burning in Portland and Medford have been found to contribute as much as 36% and 86%, respectively, to the respirable particulate mass during the fall and winter months. Estimates of the impact of vegetative burning from residential sources, however, are typically associated with uncertainties that range from 20 to 40% of the impact estimate, largely due to the high degree of variability in the chemical composition of the emissions.

Marked seasonal variations in residential wood burning emission impacts have been reported by the State of Oregon Department of Environmental Quality based on seasonal variations in atmospheric aerosol light scattering characteristics as measured by the integrating nephelometer. Comparisons of fine particle mass ($\leq$ 2.5 μm mass median aerodynamic diameter) and light scattering (B_{scat} x $10^{-4}m^{-1}$) have clearly demonstrated the usefulness of B_{scat} measurements in providing semiquantitative estimates of the impact of RWC emissions within the Northwest (7, 8). The validity of this approach to impact assessment largely rests in the fact that (a) some 80% by mass of the emissions from RWC sources are less than 1 μm in size and, therefore, within the size range that is highly efficient in scattering visible light and (b) residential burning has been implicated, by more specific chemical mass balance and radiocarbon techniques, as a major source of fine particle mass within the airshed studied (7, 8). Comparisons of diurnal variations in light scattering measurements made during summer and winter periods in the Bend and Medford, Oregon airsheds, suggest that marked changes in the B_{scat} levels during evening hours, peaking between 8 and 11 p.m., may be related to increases in the level of wood heating appliance use. Calculations of likely average winter season impacts, based on B_{scat} - fine particle relationships developed for the Medford airshed, indicate that about 39 $\mu g/m^3$ of fine particle mass may be associated with residential wood combustion emissions, as compared to a chemical mass balance-derived estimate of 37 $\mu g/m^3$ for winter months (8).

2.2 Missoula, Montana Studies

Ambient particulate TSP and fine fraction samples collected in Missoula, Montana during the 1979-1980 winter period were analyzed by four independent researchers to determine the level of residential wood combustion impact in the Missoula airshed (9). Although study period temperatures were generally warmer than that typical of winter weather, a nine day period of air stagnation was included in the field sampling program. Average fine particle RWC impacts calculated on the basis of 12 samples collected during February, 1980 averaged 37 $\pm$ 12 $\mu g/m^3$ or 68.75% of the fine particle mass depending on the investigator's analysis. Maximum 24 hour impacts of 48 $\mu g/m^3$ was measured during the study by chemical mass balance analysis.

Table 1

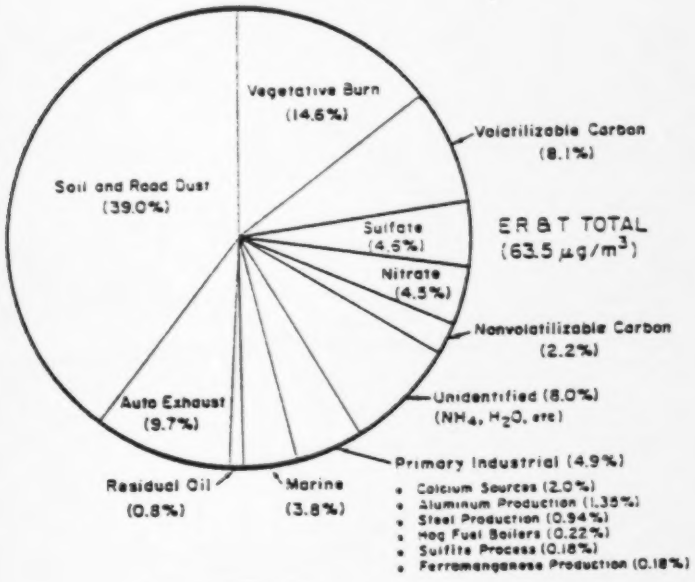
Pacific Northwest Residential Wood Combustion Impacts
(Locally Generated and Background Emissions)

City/ State	Surrounding Land Use	Particulate Matter Attributable to RWC — Annual Average				Particulate Matter Attributable to RWC — 24 Hour Worst Case			
		TSP		Respirable (1)		TSP		Respirable (1)	
Medford*		%	µg/m³	%	µg/m³	%	µg/m³	%	µg/m³
Justice Bldg.	Commercial	31.1	30.1	65.7	30.2	37	100(4)	86	82(2)
Dodge Road	Rural	33.4	8.6	58.7	8.8	9	30(3)	117	33(3)
White City	Industrial	15.3	14.3	42.2	13.5	24	52(3)	52	80(3)
Portland†									
Flavel Park	Residential	10.5	6.9	18.6	3.7	9	14(5)	36	24(6)
Industrial Air Products	Industrial	5.6	4.4	9.9	2.7	4	7(5)	1	1.2(5)
Downtown (CAMS)	Commercial	8.4	6.5	16.4	3.9	5	12(5)	7	5(5)
Carus (Background)	Rural	4.5	1.5	9.6	1.5	2	1(5)	1	5(5)
Missoula, Montana									
Lion's Park	Residential-Commercial Mix	53		68 to 75%		-	-	45	48(7)

* Ref. 3.
† Ref. 4.
(1) ≤ 2.5 µm particles.
(2) Dec. 26, 1979. Average 2, 12 hour samples. Maximum 12 hour impact, 126 µg/m³.
(3) Fall worst case day (incl. vegetative burning & veneer dryers). Includes "background" aerosol.
(4) Winter worst case day (incl. vegetative burning & veneer dryers). Includes 'background" aerosol.
(5) Worst case winter day, Jan. 27, 1978.
(6) Jan. 23, 1978. Ref. 7.
(7) Ref. 6.

FIGURE 1

SOURCE CONTRIBUTIONS TO AIR PARTICULATES
IN DOWNTOWN PORTLAND
Annual Stratified Arithmetic Average



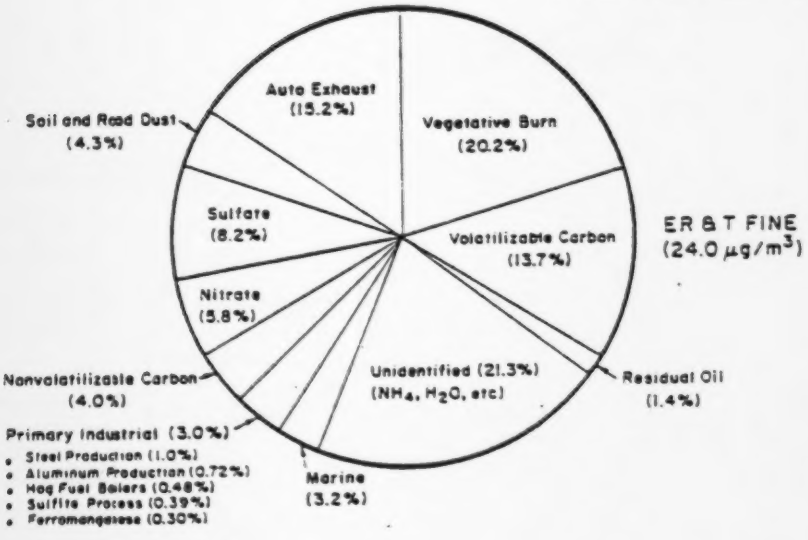
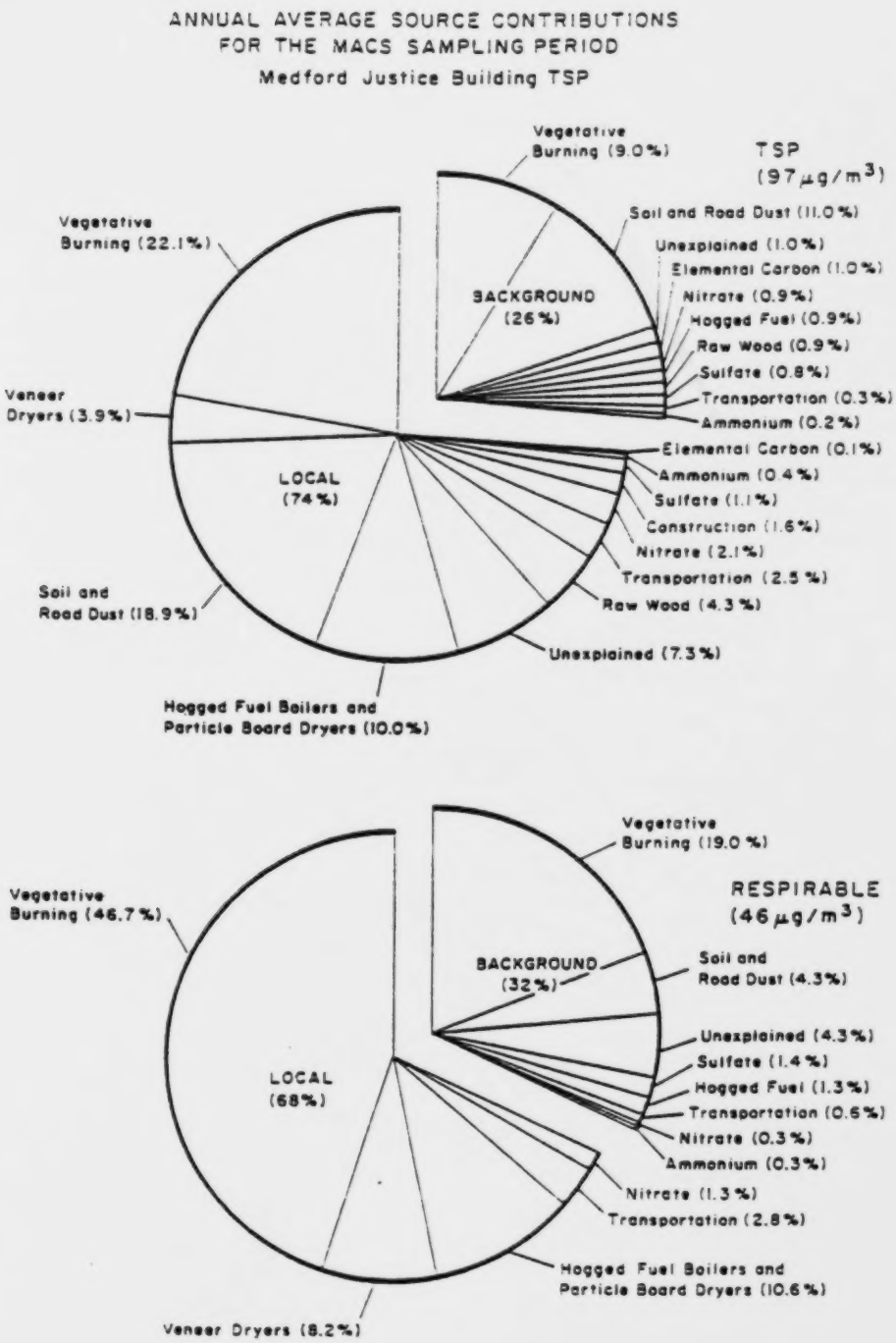


FIGURE 2


ANNUAL AVERAGE SOURCE CONTRIBUTIONS
FOR THE MACS SAMPLING PERIOD
Medford Justice Building TSP
TSP
(97 μg/m3)
Vegetative Burning (9.0%)
Soil and Road Dust (11.0%)
Unexplained (1.0%)
Elemental Carbon (1.0%)
Nitrate (0.9%)
Hogged Fuel (0.9%)
Raw Wood (0.9%)
Sulfate (0.8%)
Transportation (0.3%)
Ammonium (0.2%)
BACKGROUND
(26%)
Vegetative Burning (22.1%)
Veneer Dryers (3.9%)
Elemental Carbon (0.1%)
Ammonium (0.4%)
Sulfate (1.1%)
Construction (1.6%)
Nitrate (2.1%)
Transportation (2.5%)
Raw Wood (4.3%)
LOCAL
(74%)
Soil and Road Dust (18.9%)
Unexplained (7.3%)
Hogged Fuel Boilers and Particle Board Dryers (10.0%)
RESPIRABLE
(46 μg/m3)
Vegetative Burning (19.0%)
Soil and Road Dust (4.3%)
BACKGROUND
(32%)
Unexplained (4.3%)
Sulfate (1.4%)
Hogged Fuel (1.3%)
Transportation (0.6%)
Nitrate (0.3%)
Ammonium (0.3%)
Vegetative Burning (46.7%)
Nitrate (1.3%)
Transportation (2.8%)
LOCAL
(68%)
Hogged Fuel Boilers and Particle Board Dryers (10.6%)
Veneer Dryers (8.2%)

2.3 Task 1 (Ambient Air Quality Impact) Findings

The ambient air quality impact of RWC emissions in eight Pacific Northwest cities was studied during the 1980-1981 space heating season (10). Seventy-five selected, worst case fine particle samples collected in Seattle, Spokane, Yakima, Tacoma and Longview, Washington; Boise, Idaho; Portland and Medford, Oregon were chemically analyzed for polynuclear aromatic hydrocarbons (PNA), 35 trace elements and carbon. The air quality impact of RWC and other emission sources was determined by chemical mass balance and carbon-14 analysis methods. Residential wood combustion impacts measured during this study were largely measured during the month of February, 1981 - a period during which average heating loads were less than those which typically occur during periods of peak space heating demand. Results reported from the Task 1 analysis, therefore, represent high impact days selected from a group of samples collected during a period of relatively moderate weather conditions. Higher impacts may occur during periods of greater space heating demand and poorer atmospheric dispersion.

Results from these studies (Table 2 and Figure 3) have clearly identified the importance of RWC emissions as a major contributor to the fine particle and TSP mass. Source apportionment results typically assigned 60 to 75% of the fine particle mass to RWC emissions during 24-hour worst case conditions. Impacts exceeding 50 $\mu g/m^3$ were measured at residential sites in Seattle, Spokane, Portland, Medford and Boise. The maximum impact (128 $\mu g/m^3$, 8-hour average, upper limit estimate) was recorded at the Boise residential site; note that all Boise results are based on inhalable ($\leq$15 m) particulate, not fine particulate. Measurement of PNA compounds present on selected high RWC impact samples showed that urban concentrations of these carcinogenic compounds were typically an order of magnitude higher than similar measurements made at background sites. Expressed in terms of exposure to benzo(a)pyrene (B(a)P), a PNA compound with demonstrated carginogenic properties, exposure to B(a)P concentrations associated with RWC emissions of 4.1 ng/m^3 (arithmetic mean value for residential sites) 24-hour average is comparable to the exposure related to smoking approximately four cigarettes per day. At the maximum B(a)P concentration measured during the study (11.1 ng/m^3, 24-hour average), the dosage is equivalent to 11 cigarettes per day. Although the measured PNA concentrations should be of concern, no direct dose-response relationships are currently available upon which to base a quantitative assessment of public health risk.

Comparisons of RWC impacts in relation to concurrent TSP measurements suggest that from 25 to 44% of the TSP mass measured in residential areas was contributed by RWC emissions during worst case impact situations. Initial estimates, based on inhalable particulate samples, indicate that as much as 60% of the Boise TSP mass may be related to wood burning. Results from the Boise study, however, need to be further verified by analysis of fine particle (< 2.5 µm) rather than inhalable ($\leq$ 15 µm) particulate samples. Direct analysis of the importance of RWC emissions in relation to TSP air quality standards is not possible because of constraints imposed by the study design.

Table 2

CMB Estimates of RWC Impacts
(October 1980 - March 1981)
Fine Particle Fraction
($\mu g/m^3$)

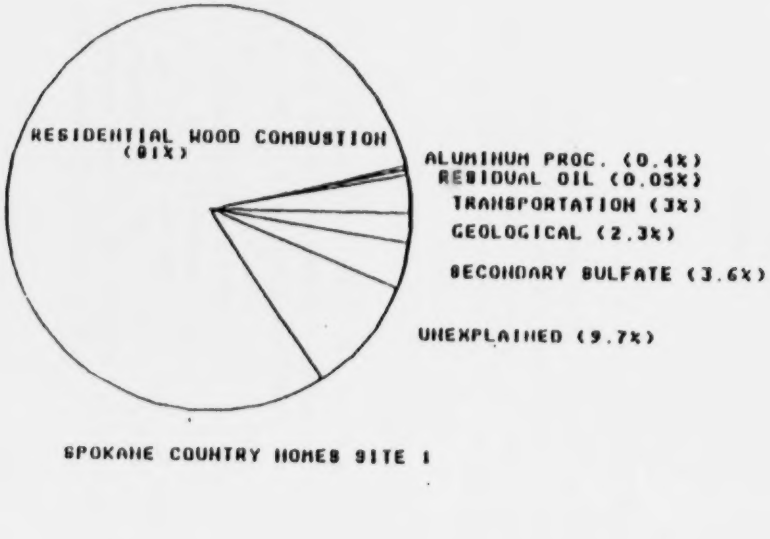
City	Site No.	No. of Samples	Site Name[3]	Average RWC Percent of Fine Mass	Average Fine Mass	Average Impact	24 Hour Maximum	24 Hour Minimum	Average RWC Background	Locally Generated RWC Impact
Washington										
Spokane	1	15	Country Homes (R)	81.0	55.0	44.5 ± 11.5	68.1 ± 16.0	19.9 ± 12.6	6.8 ± 3.4	37.7
Spokane[A]	13	1	County Health (C)	64.7	53.1	34.3 ± 21.3	-	-	6.8 ± 3.4	27.5
Spokane[A]	14	4	Crown Zellerbach (I)	45.3	37.0	16.7 ± 14.9	19.1 ± 17.3	14.9 ± 12.3	6.8 ± 3.4	9.9
Seattle	3	10	Newport Way (R)	83.8	36.1	30.2 ± 8.6	48.8 ± 13.8	8.2 ± 2.6	9.4 ± 2.8	20.8
Seattle[A]	8	2	South Park (R)	65.8	-	-	68.2 ± 19.9	65.9 ± 19.6	9.4 ± 2.8	57.7
Seattle[A]	10	3	Georgetown (I)	73.4	39.7	29.1 ± 20.2	35.5 ± 24.3	20.4 ± 15.3	9.4 ± 2.8	19.7
Tacoma	9	4	Fire Station #12 (I)	74.9	47.0	35.2 ± 25.8	44.3 ± 32.2	20.3 ± 14.6	-	
Yakima[A]	11	4	Courthouse (C)	93.1	53.8	50.0 ± 34.9	55.1 ± 32.4	48.0 ± 37.7	-	-
Longview[A]	12	4	City Shops (C)	61.4	41.8	25.6 ± 17.8	40.5 ± 24.1	14.2 ± 9.2	-	
Idaho										
Boise[A]	15	9	Fairview & Liberty St. (C)	69.5	121.8	84.7 ± 22.3[1]	127.9 ± 29.9[1,4]	50.0 ± 13.4[1]	-	
Oregon										
Portland	5	8	Whitman School(R)	68.5	40.0	27.4 ± 10.3	49.0 ± 13.6	13.7 ± 3.9	7.4 ± 5.2	20.0
Medford[A]	7	1	Courthouse (R)	-		-	62.2 ± 19.0		-	

Notes:

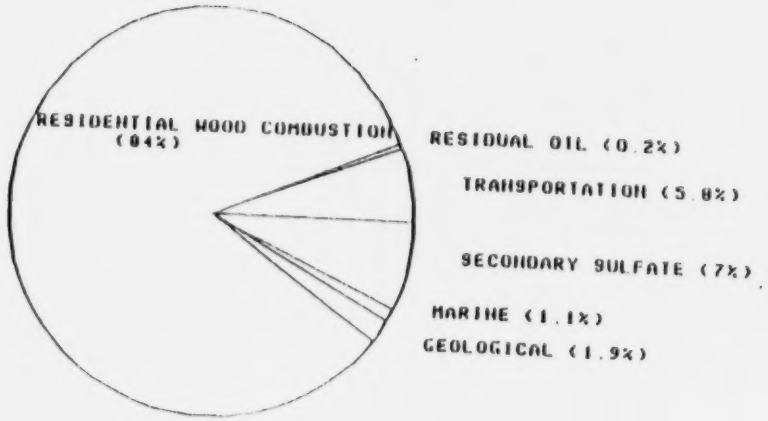
[1] Inhalable Fraction (≤ 15 μm) - upper limit RWC impact estimates
[2] 8 hour sample.
[3] Site key
R - Residential
C - Commercial
I - Industrial

[A] Historical Samples

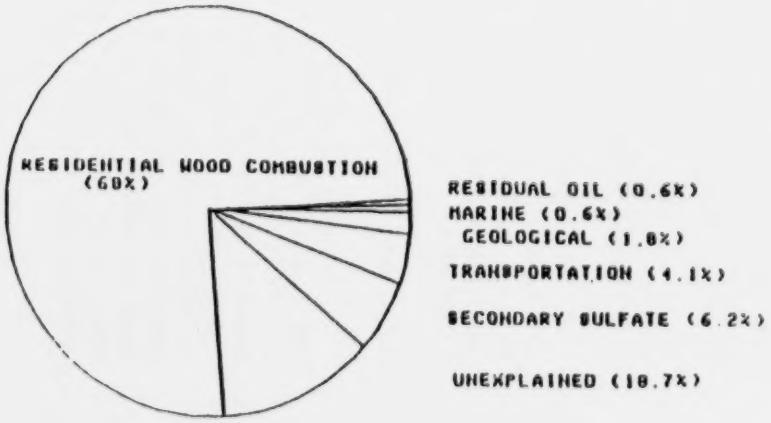
Figure 3
Average 24 Hour Worst Case
Source Contributions
-Fine Particle Fraction-
(October, 1980-March, 1981)



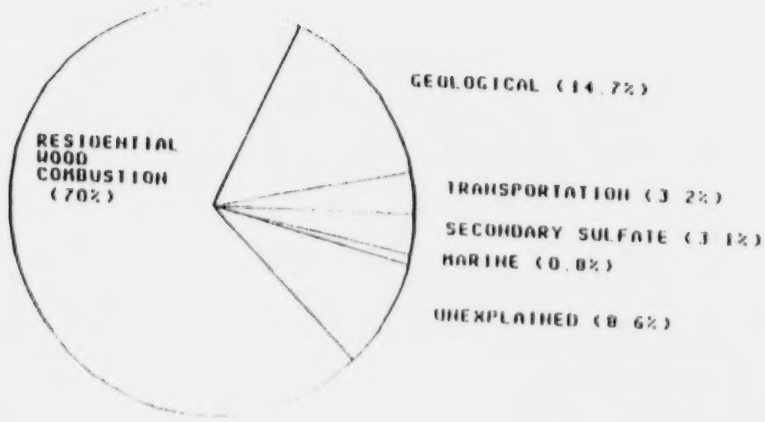
SPOKANE COUNTRY HOMES SITE 1



SEATTLE NEWPORT WAY SITE 3
(Bellevue)



PORTLAND MARCUS WHITMAN



BOISE FAIRVIEW & LIBERTY STS
(Inhalable Fraction $\leq$ 15μm)

2.4 Trends in RWC Particulate Impacts

An evaluation of RWC air quality impact trends during the recent past provides an opportunity to place the results from recent studies of ambient air quality impacts into historical perspective. Trend studies reported in Task 3, Part III, have attempted to determine the short term trend in wood fuel use by examining the impact of urban wood combustion on various measures of air quality likely to be impacted by increased wood use (11). Trends in evening carbon monoxide concentrations, the organic content of the TSP aerosol, light scattering properties of the atmosphere and coefficient of haze ("soiling index") measurements were examined as possible trend indicators since an insufficient data base of chemical mass balance-derived RWC impact data is available. Limitations in the measurements and adequacy of the historical data base, however, restricted the analysis to light scattering measurements (B_{scat}) at commercial land use sites in Seattle and Portland during the 1978-1981 heating seasons (October-March).

Trends in B_{scat} measurements were normalized for variations in heating degree days and wind speed to minimize variations due to meteorological factors, averaged to represent a single heating season and bivariate plots of B_{scat} vs heating season prepared. Linear regression analysis of the data suggests a 6-8% per year increase in heating season average B_{scat} values, suggesting that concentrations of fine particles during the heating season may have increased in both Portland and Seattle in recent years. Emission inventory and dispersion model analysis for the Portland airshed during the 1977-1978 period indicate that fine particle impacts from other major sources should decrease or only slightly increase, suggesting that increases in B_{scat} measurements during the heating seasons are likely associated with increases in RWC emissions. Although the results of this analysis are, at best, tentative, the rate of increase suggested by this analysis is the same as that estimated from records of firewood supplied by the national forests.

3.0 PROJECTIONS OF FUTURE RWC IMPACTS

Development of projections for future RWC impacts require (a) estimates of the likely future growth of RWC emissions and (b) establishment of a relationship between emission strength and air quality impact. This section discusses each of these elements, related assumptions and projections based on the methodology described.

3.1 Wood Fuel and Emission Projections

Studies of short term trends in wood use have been conducted to support the light scattering trend analysis described above and as a means of understanding the changes in air pollution problems that have occurred in many Pacific Northwest communities during the past 3-4 years (14). Analysis of trends in the volume of firewood removed from forest lands under cutting permits, surveys of household firewood use and trends in the sale of wood burning appliances have been examined, but only the wood cutting permit data base is sufficient to establish possible trends. Table 3 summarizes the results of the short term trend analysis, suggesting a 6-8% maximum annual average increase in wood fuel use or a 34-47% increase between 1980 and 1985.

Table 3

Summary of Short Term Trends
in Wood Fuel Use*

Parameter	Heating Seasons	Est. Annual Rate of Increase (%)
A) Cutting Permit Trends		
Seattle, Washington	1975-1980	7.8-7.9
Portland, Oregon	1976-1981	6.5
Spokane, Washington (Colville, N.F.)	1977-1980	5.7
Spokane, Washington (Idaho Panhandle N.F.)	1977-1981	7.2-7.3
B) Light Scattering Coefficient ($B_{scat} \times 10^{-4} m^{-1}$)		
Seattle, Washington (Kent site)	1978-1981	7.9
Portland, Oregon (CAMS site)	1978-1981	5.7

*After Table 7, Task 3. Ref. 11.

Long term projections of wood fuel use for the period 1985-2000 were prepared using a state-of-the-art computer simulation model which considered the estimated cost of wood and alternative fuels, population and household growth projections, heating requirements, the mix of fuels used in the community and other factors. Projections of wood fuel use are, however, primarily driven by the magnitude of potential cost savings associated with heating by wood rather than other fuels. The model was modified to include fireplace use as well as wood stoves and furnaces. Because wood stoves typically emit more than twice as much particulate per ton of wood burned than fireplaces, and given the relative increase in the use of wood stoves over fireplaces, adjustment in wood fuel use were required to obtain estimates of future particulate emissions.

Projections for the Portland area show that total wood use is expected to increase by 37% between 1980 and 2000 or, in terms of particulate emissions, by 72% by 2000. For Seattle, total wood use is projected to increase by 19% between 1980 and 1985 or by 40% in terms of particulate emissions. Projections for Spokane show an overall 9% increase in wood use and a 26% increase in emissions based on most probable case assumptions. Table 4 shows these projections for each 5 year period between 1980 and 2000.

Table 4

Projections of Residential Wood Fuel Use
and Corresponding Particulate Emissions

Year	Stove/Furnace Wood Usage (1)	Fireplace Wood Usage (1)	Total Wood Usage (1)	Total Particulate Emissions (2)
Portland Metropolitan Area				
1980	150	190	340	9.3
1985	240	190	430	12.8
1990	240	170	410	12.5
1995	300	150	450	14.5
2000	340	140	480	15.9
City of Seattle				
1980	45	110	155	3.7
1985	85	100	185	5.1
1990	85	100	185	5.1
1995	90	100	190	5.3
2000	85	100	185	5.1
City of Spokane				
1980	28	93	121	2.7
1985	42	84	126	3.1
1990	45	81	126	3.2
1995	51	78	129	3.4
2000	54	75	129	3.4

(1) 10^3 cords/year
(2) 10^3 tons TSP/year
After Table 1, Task 3. Ref. 11

3.2 Wood Use - Air Quality Relationships

Development of a relationship between wood use and resulting air quality impact forms the foundation of future projections of RWC impact given estimates of future wood fuel use. Numerous investigators have described the use of wood as a space heating fuel and energy related issues (23-24,28,36,37,39, 44-65,70,72,73,77,100,114,123-125,131,134,141,148,160,165,168,173,191,203,204, 229-231,235,241,249-251,273,278,294-299,313,317,321,332,333). However, to establish this relationship for a specific city required development of data on woodburning activity during February, 1981 in Portland, Seattle and Spokane. This data was gathered within a one square mile area around each air monitoring site to insure that wood use survey results could be related to ambient impact estimates.

The wood use surveys were based on a random selection of 800 households within a one-square mile area around each residential air monitoring site; questionnaire surveys were mailed to each household and the results statistically analyzed. The highest rate of response (58%) occurred in Spokane, while Portland and Seattle responses were 36 and 48%, respectively (10). Summary statistics were obtained for each survey area in each of a number of categories related to wood fuel use in the home.

Table 5 summarizes the survey results used in establishing wood use - air quality relationships for each of the three communities studies. Approximately 49, 18 and 19% of the wood burned during February, 1981 in Portland, Seattle and Spokane was burned in wood stoves, with the balance burned (primarily) in home fireplaces. Given the total number of cords burned during February in each community, an estimate of the weight of one cord of wood and a particulate emission factor for wood stoves and fireplaces, an estimate of likely TSP emissions within one square mile of the monitoring sites was made. The emission estimates can then be used in association with concurrent air quality impact estimates and projections of future emissions to estimate future air quality impacts given the following assumptions and data limitations:

1. Representative Impact Measurements: Estimates of RWC impacts must be representative of the heavy wood use areas within the communities studies. As noted in the Task 1 document, extreme care was taken during siting of the samplers to insure that (a) samples were not subject to impact from any single nearby source; (b) sites were located in residential areas where, based on surveys of wood stove stacks and wood piles, wood burning was known to be occuring; and (c) sampler exposure, height above ground and setback from roadways were determined to be consistent with 40 CFR, Part 58 EPA siting criteria.

2. Similar Dispersion Conditions: Dispersion conditions during the periods selected for analysis must be assumed to be typical of those likely to occur in future years. Because the measured RWC impacts are a function of emission strength and meteorology at the time of sampling, the measured impacts reflect both conditions and, while impact corrections have been made to emission strength term, no analysis or adjustments to the measured impacts have been made relative to the meteorology. As noted in Task 1, impact estimates made during February, 1981 reflect the relatively mild weather conditions that occurred during that time, such that the study results represent reasonable, rather than extreme, worst cast conditions.

Table 5

Wood Fuel Use[1]
Household Survey Results
(Month of February 1981)

CATEGORY	PORTLAND	SEATTLE	SPOKANE
Wood Stove Use			
• Days Used	22.6	20.0	23.3
• Hours Per Day	10.0	10.6	14.0
Fireplaces & Inserts			
• Days Used	16.4	8.9	12.2
• Hours Per Day	7.6	4.1	6.3
Wood Burned (Cords)			
All Devices	433.6	303.7	326.5
% Wood Stoves	49.3	18.6	19.5
% Fireplaces	50.7	81.4	80.5
Wood Stoves (mean ± standard deviation)*	.103 ± .33	.039 ± .166	.069 ± .368
Fireplaces (mean ± standard deviation)*	.079 ± .31	.159 ± .243	.246 ± .437
Furnaces (mean ± standard deviation)*	.007 ± .067	.0	.002 ± .048
TSP Emissions (Tons)**			
Wood Stoves	8.41	2.22	2.50
Fireplaces	3.84	4.33	4.59
Total	12.24	6.55	7.09
Average Worst Case RWC Impacts on fine particle fraction (24-hr, $\mu g/m^3$)			
Urban-Residential Site †	23.1	34.7	44.7
Background (average)	9.8	9.5	13.1
Locally generated impact	13.3	25.2	31.6
Number of observations	6	5	8

(1) Survey results are from a one-square mile area around each residential air monitoring site.

* Average wood use, all households.

** Assuming 1.75 tons wood/cord; fireplace and wood stove emission factors of 20 and 45 lbs/ton, respectively.

† Mean RWC impact on fine particle fraction ($\leq 2 \mu m$) from samples collected during February 1981 only; (since these data are for February only the reported values will not exactly compare to the Table 2 values for October 1980 - March 1981).

3. Application of Emission Estimates: The rate of change in the projected particulate emission estimates (Task 3, Table 4) are assumed to reflect the likely change in emissions in the vicinity of the monitoring site. Since the emission projections were developed for the urban area in which sampling was conducted, this assumption further requires that the spatial distributions of the RWC emissions remains relatively unchanged over time. Major increases in emission density, for example, in an area predominately upwind of the receptor could increase RWC impacts to a greater degree than anticipated.

4. Importance of Nearby Sources: RWC emissions located within one square mile of the monitoring site are predominately responsible for the measured RWC impact, or conversely, that RWC sources outside of the survey area are relatively unimportant contributors. While the RWC area source emissions located in near proximity to the monitoring site will collectively form a major portion of the impact due to relatively non-dispersed nature of the plumes, the large relative magnitude of all other RWC emission sources within the airshed may also be important, Determination of the relative importance of the two subgroups would require a rather comprehensive dispersion modeling study. Fortunately, the technical basis of the RWC impact projections does not rely heavily on this assumption.

5. Background Impacts: Background RWC impacts are assumed to remain constant over the next 20 years. Since no data is available upon which to base air quality projections of the background impacts, the total RWC impact estimate (locally generated plus background) should be viewed as conservative.

6. Other Locations: Impact projections cannot be developed for other locations within the community which, because of future changes in emission density, may experience greater impacts than the locations studies here.

7. Limited Data Set: Impact projections are based on average RWC impacts calculated for valid samples collected during February, 1981. As noted in Table 5, relatively few (5-8) observations are available upon which to base an impact/emission relationship.

The most critical assumptions employed in this analysis are that (a) the emission projections made for the entire Portland, Seattle and Spokane airsheds also apply to sources within one square mile of the monitoring site and (b) that the limited number of RWC impact estimates accurately reflect the magnitude of nearby emissions (i.e., that the impact emission ratio is accurate.

3.3 Impact Projections (1981 - 2000)

Table 6 presents projections for RWC impacts given these assumptions. The estimates assume that the particulate emission projections listed in Table 4 and noted below in terms of percent change will result in an equivalent change in air quality impact.

Table 6

Estimated Future RWC Fine Particle Impacts†
(24-Hour Reasonable Worst Case)

City/Site	Year	Particulate Emissions (Tons/Month)(1)	Projected RWC Impacts†† ($\mu g/m^3$) Local(2)	Total(3)	Projected % Change In Emissions Over Next Five Years
Portland (Marcus Whitman)	1981	12.2	13.3*	23.1*	37.6%
	1985	16.7	18.3	28.1	- 2.3%
	1990	16.4	17.8	27.6	16.0%
	1995	19.0	20.6	30.4	9.6%
	2000	20.8	22.5	32.3	-
Seattle (Newport Way)	1981	6.5	25.2*	34.7*	37.8%
	1985	8.9	34.7	44.2	0.0
	1990	8.9	34.7	44.2	3.9%
	1995	9.2	36.0	45.5	- 3.9%
	2000	8.9	34.7	44.2	-
Spokane (Country Home)	1981	7.1	31.6*	44.7*	14.8%
	1985	8.1	36.3	49.4	3.2%
	1990	8.3	37.5	50.6	6.2%
	1995	8.8	39.8	52.9	0.0
	2000	8.8	39.8	52.9	-

† First order approximations.

†† Fine particle ($\leq 2.5\ \mu m$) fraction.

* Measured data; February 1981.

(1) Emissions within a one-sqaure mile area of the monitoring site based on February 1981 survey results.

(2) Average worst case impact associated with locally generated RWC emissions, only. Based on 1.1, 3.8 and 4.5 $\mu g/m^3$ of impact per ton of emissions and emission projections for Portland, Seattle, and Spokane, respectively.

(3) Average worst case impact associated with local and background emissions. Lower limit estimate . Assume constant background contribution.

Projections of wood used, TSP emissions and total RWC impacts listed in Tables 4 and 6 are presented in Figure 4. The higher air quality impacts per ton of emission noted in Seattle and Spokane reflect the more restrictive dispersion meteorology associated with samples taken in Seattle and Spokane. While the data presented in Table 6 and Figure 4 can provide a good indication of likely trends in RWC impacts, limitations imposed by the assumptions and data sets used restrict quantitative uses of the projections to first order approximations. Due to the tenuous nature of the projection methodology and the difficulty in developing a valid impact/emission estimate for a single day, no attempt has been made here to project extreme worst case impacts. Rather, the estimate represents an average, worst case 24-hour fine particle mass impact. Development of a more quantitative understanding of emission-air quality relationships will require a much more intensive effort utilizing urban dispersion models that have been validated with respect to receptor model (e.g. CMB model) estimates.

4.0 DISCUSSION OF PROJECTION RESULTS

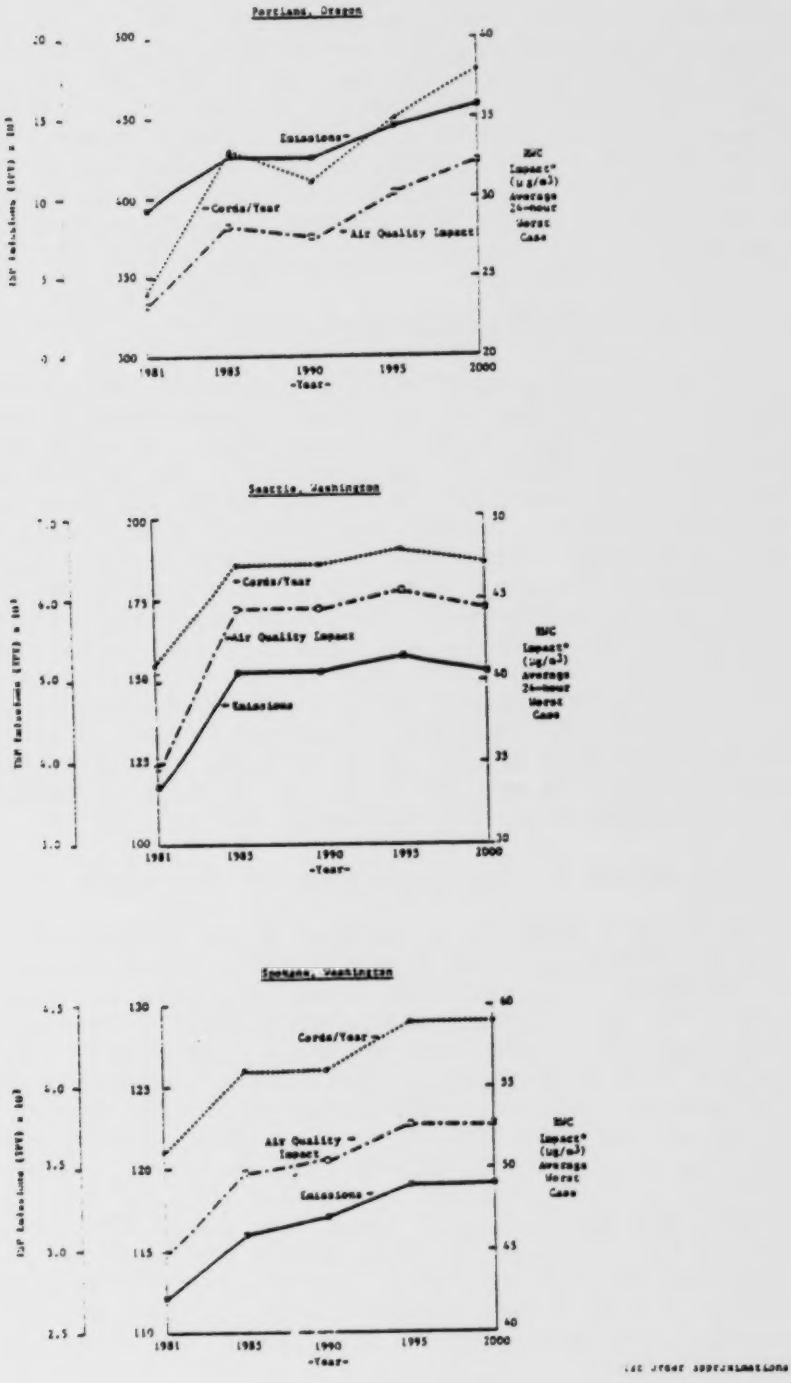
The RWC impact projections for the period 1981 to the year 2000 represents 40%, 27% and 21% increases in average worst case impacts in Portland, Seattle and Spokane, respectively. In terms of concentration, these figures represent an additional 9.2, 9.5 and 8.2 $\mu g/m^3$ of fine particulate mass burden to the airshed during poor ventilation winter days. These impacts, however, represent average, reasonable worst case 24 hour conditions, rather than a single actual worst case condition that has occurred in history. Projections, for example, developed by the State of Oregon Department of Environmental Quality, for 1987 RWC impacts to the TSP fraction suggest a 53 $\mu g/m^3$, 24 hour impact at a Portland residential site during worst case winter conditions - an estimate based on dispersion model analysis of a single 24-hour period of poor ventilation (13). In addition, samples analyzed as part of the Task 1 effort demonstrated 24-hour impacts markedly higher than the year 2000 projections, demonstrating the importance of clearly defining the meteorological and emission strength basis for the impact analysis.

4.1 Implications for Future Air Resource Management

As national interest in revision of the current TSP national ambient air quality standard turned toward adoption of a 10 µm particulate matter (PM_{10}) standard, the importance of RWC emissions to attaining and maintaining a new particulate standard will become increasingly evident. Studies conducted by the State of Oregon, for example, (Section 2.1) have determined that worst case 1987 RWC emission impacts in residential areas will account for 44% of the TSP, about 65% of the inhalable particulate mass ($\leq$15 µm) and about 80% of the PM_{10} mass, assuming a 20% reduction in impact from paved and unpaved road dust emissions. When considered in relation to (a) the rapid and potentially uncontrolled growth in RWC emissions; (b) the associated impact that these fine particles will have on the visual clarity of the atmosphere; (c) the potential public health implications; and (d) consequences to air resource management, the impact projection presented here signals the strong need to conduct a more intensive analysis of future impacts in relation to current and proposed air quality standards.

FIGURE 4

RWC Impact Projections (1981 - 2000)



* 24-hour approximations

The implications of an increase in fine particle mass impacts by RWC emissions on the visibility degradation is of special interest to Pacific Northwest communities with scenic vistas. Urban visibility degradation is primarily a result of the scattering and absorption of light by fine particles. In most cases the light absorption coefficient is small in comparison to the light scattering (B_{scat}) component. The relationship between B_{scat} and fine particle mass concentrations has been studied by a number of researchers (15,16).

Regression analysis of concurrent B_{scat}-fine mass measurements made as part of the PACS program (4) was also conducted by Shaw and co-workers (7). Results of the analysis indicated:

(a) An excellent correlation exists between B_{scat} and fine mass concentrations (B_{scat} = 0.113 + 0.047) mass where n = 404 and r = 0.934. Figure 5 illustrates this relationship.

(b) The light scattering efficiency of sulfate, nitrate and carbon aerosol were all equivalent (5 m^2/g) and collectively account for 86% of the light scattering due to aerosols.

(c) The only significant contribution from primarily aerosol sources to B_{scat} was from vegetative burning - the major source of primary carbon aerosol. This component accounts for 18% of the light scattering, on an annual average basis.

Studies of visual range (V_r), the distance at which a large black object is just visible, have shown that under a limited set of conditions, V_r is well correlated with B_{scat} (commonly about 0.9) measured in relatively polluted conditions where pollutants are homogenously distributed. For non-absorbing atmospheres ($B_{ext} = B_{scat}$) a relationship of $V_r = 3.9/B_{scat} + 0.01$ has been found (21) where:

V_r = visual range (Km)
B_{scat} = aerosol scattering coefficient (Km^{-1}) at 550nm
0.01 = standard Rayleigh scattering value (Km^{-1})

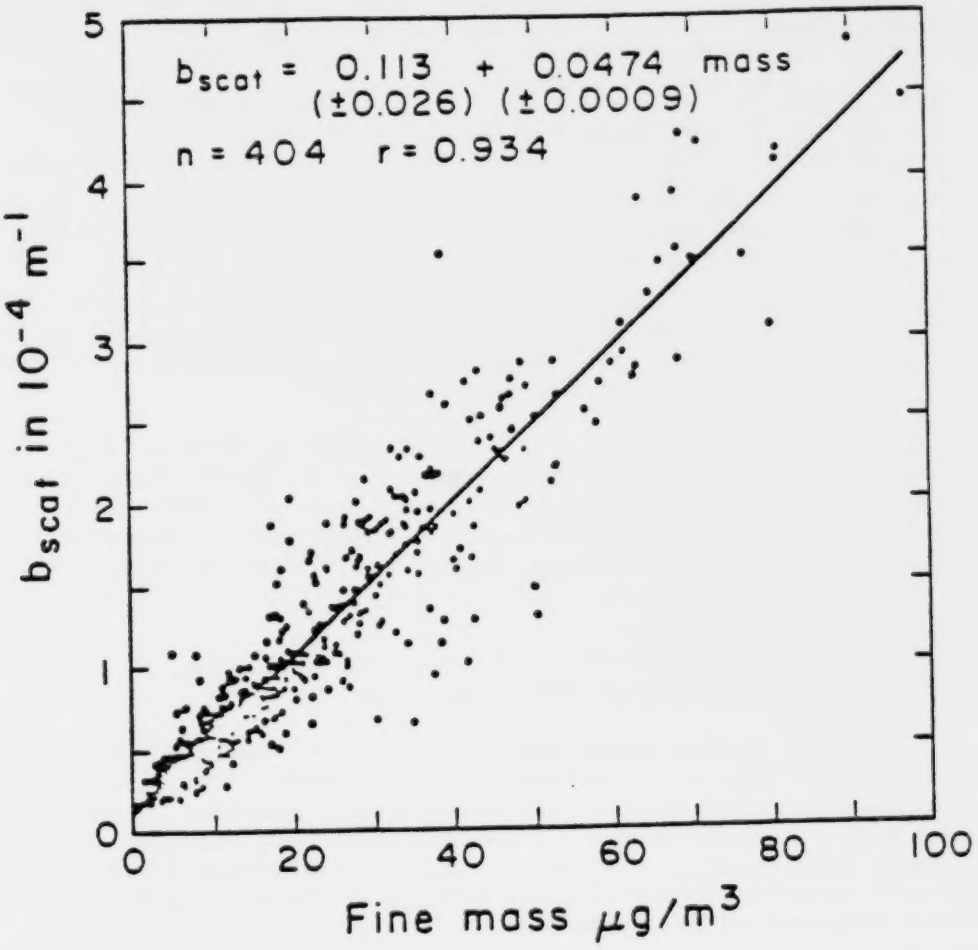
If, under average worst case conditions, RWC impacts increase by approximately 10 $\mu g/m^3$ by the year 2000, the above relationships for Portland would suggest a resultant 24 hour average B_{scat} increase of about 0.6 Km^{-1}, or expressed in terms of V_r, a resultant additional decrease in visual range of about 6 Km, or about 4 miles. This is a convervative estimate which does not consider light absorption effects or the association with elemental carbon component of RWC emissions.

Expressed in terms of airshed capacity, increases in RWC impacts may represent an important factor in (a) limiting emission growth of other sources in the airshed, (b) exacerbating and/or expanding the extent of the nonattainment areas or (c) resulting in additional control requirements on other sources to offset RWC emission growth.

For example, cost estimates developed as part of the Medford, Oregon TSP control strategy suggest that reduction of 1 $\mu g/m^3$ in annual TSP mass concentration for the following control measures will result in the costs noted below (19):

Figure 5

B_{scat} - Fine Aerosol Mass Relationship
Portland, Oregon



Relationship between light-scattering coefficient and fine aerosol mass for 24 hour samples from five sites. Solid line represents the linear regression of B_{scat} on mass. Ref. 17.

Control Measure	$ year/ug/m^3
Small Hogged fuel boilers (0.1 gSCF)	$ 130,000
Large Hogged fuel boilers (0.01 gSCF)	$ 120,000
Small Cyclones	$ 130,000
Veneer dryers	$ 500,000

4.2 Potential Mitigating Measures

The air quality and emission projections used in preparation of this document include no inherent assumption of emission mitigation, other than the economics of fuel use. Control strategy options are discussed in Task 6, while Task 4 is a technical analysis of wood stove combustion principles, design considerations and operating techniques (20,21). A brief discussion of the findings of these tasks are included here to place the air quality impact projections into proper perspective, as it is likely that a number of mitigating actions will be adopted by state, city or regional regulatory agencies within the period covered by the projections.

Numerous investigators have reported on potential control options (26,38,40,97,152,163,164,180,192,246,303,329,339) and regulatory approaches (96,104,115,136,153-155,221,224,243,252-254,263,270) to mitigating RWC impacts. The design and operation of wood burning appliances has been studied by many researchers (66-68,103,177,179,210,223,240,274,275). Results from these programs have clearly demonstrated the importance of these factors in determining emission rates of pollutants and the efficiency of the appliance. Variables such as charge rate, fuel and combustion air regulation, all operator-dependent variables, greatly influence the emission rate and heating efficiency. Minimizing emissions, while maximizing efficiency requires:

(a) that stove be sized to encourage operation at high burning rates

(b) avoiding overcharging of the appliance with wood and overnight "banking" of fires

(c) use of properly seasoned wood

(d) fireplace operation only during periods of mild temperatures with the use of door enclosures and

(e) addition of catalyst and/or automatic thermostats or other design changes (e.g., secondary air) to improve combustion efficiency (effectiveness not yet proven or established).

The Task 4 report concludes that a considerable reduction in contaminants could be realized by providing more public information and education on proper appliance firing techniques. These conclusions are consistent with the greater body of literature describing the nature and quantity of pollutants emitted from wood combustion processes (75,77,80, 81,89,91-93, 1-1,1-6,116-118,121,126,128-130,132,133,137,142,146,156,162, 167,169,170,174,181,184,187-189,195-199,207,216,228,236,237,245,255-260, 266-269,271,272,277,283-285,281,301-305,307-311,313,316,327,328,331).

5.0 Summary and Conclusions

The use of wood as a residential space heating fuel in the Pacific Northwest has increased markedly in the past four years. The apparent increase in wood use, as indicated by trends in wood stove sales, emission inventory and ambient air monitoring information collectively point toward a problem of growing concern related to future air quality management and public health issues. In light of these concerns, a study of the current and likely future impacts of RWC emissions in major population centers in Oregon, Washington and Idaho was conducted during the 1980-81 heating season. The study design incorporated concurrent measurements of worst case RWC impacts, development of an RWC emission inventory data base for three cities and estimates of likely future emissions, given certain trends in energy use and economics. Through development of a RWC impact/emission inventory relationship, air quality impact projections have been prepared and likely implications have been examined.

Studies of worst case 24-hour RWC impacts measured during the 1980-81 space heating season have been developed as described in Task 1 and compared to those derived from aerosol studies conducted in Oregon and Montana. Results from these studies have clearly identified the importance of RWC emissions as a major contributor to the fine ($\leq 2.5\ \mu m$) and TSP mass. Source apportionment results developed by Chemical Mass Balance and confirmed by radiocarbon techniques, typically assigns 60 to 75% of the fine mass to RWC emissions during 24-hour worst case conditions. Impacts of 50 $\mu g/m^3$ or greater from wood smoke were measured at residential sites in Seattle, Spokane, Portland, Medford and Boise, with the maximum impact (128 $\mu g/m^3$, inhalable particulate fraction 8-hour average upper limit estimate) recorded at the Boise residential site. Concentrations of polynuclear aromatic compounds present in selected samples suggest that urban concentrations are a factor of ten higher than those measured in rural areas. Exposure to average B(a)P concentrations associated with wood smoke is comparable to the exposure associated with smoking four cigarettes per day. At the maximum B(a)P concentrations (11 ng/m^3), the dosage is equivalent to about 11 cigarettes per day. Since no direct dose-response relationships are available for B(a)P exposure, a quantitative assessment of public health risk cannot be determined.

Analysis of the trends in firewood use during the past 3-4 years and estimates of likely short-term trends have suggested a 6-8% maximum annual average increase in wood use during the 1980-85 period or a total maximum increase for the 5 year period of 34-47%. Long-term projections (1985-2000) developed by a computer simulation model given the cost of wood and alternative fuels, population growth and wood stove-fireplace use trends indicate a wood fuel use increase of 41%, 26%, and 7% by the year 2000 in Portland, Seattle, and Spokane, respectively, resulting in a 72% increase in RWC emissions by the year 2000 in Portland, 40% in Seattle, and a 26% increase in Spokane.

Wood use-air quality relationships developed for Portland, Spokane and Seattle for the period of February 1981 have been used, in association with the emission projections to estimate future impacts related to wood burning. A direct, proportional relationship between emission growth and wood smoke impact assumed in this analysis limits the accuracy of the projections to first order approximations. The impact projections for the period 1981 to 2000 represent a 40, 27, and 21% increase in average worst case impacts in Portland, Seattle, and Spokane, respectively. These figures represent an additional 9.2, 9.5, and 8.2 $\mu g/m^3$ fine particulate burden on the airsheds in each of the above cities.

The implications of these projections to air resource management in the Pacific Northwest are numerous, especially when considered in relation to the absence of any regulatory control on the growth of RWC emissions and their impact on the visual clarity of the atmosphere. Based on established relationships between visual range, light extinction and fine particle aerosol mass in Portland, the projected 10 $\mu g/m^3$ increase in RWC impacts during the year 2000 would contribute to a decrease of about 4 miles in visual range during cold periods of poor atmospheric ventilation in addition to the existing visibility impairment (estimated at approximately 9 miles) from RWC. Other implications may include limiting the emission growth of other sources in the airshed, expanding the extent of nonattainment areas and requirements placed on other sources to offset RWC emission growth.

6.0 References

1. Residential Solid Fuels, Environmental Impacts and Solutions. J.A. Cooper and D. Malek, Eds., Oregon Graduate Center, Beaverton, OR 1981.

2. J.A. Cooper, "Environmental Impact of Residential Wood Combustion and It's Implications," Journal of the Air Pollution Control Association, Vol. 30, No. 8, August, 1980.

3. R.T. DeCesar and J.A. Cooper, "Medford Aerosol Characterization Study," Final Report to the State of Oregon Department of Environmental Quality, February, 1981.

4. J.A. Cooper and J.G. Watson, "Portland Aerosol Characterization Study," Final Report to the State of Oregon Department of Environmental Quality, July, 1979.

5. J.E. Core, J.A. Cooper and J.E. Houck, "A Study of Residential Wood Combustion; Task 1 - Ambient Air Quality Impact Analysis", prepared for U.S. EPA, Region X, December 1981.

6. J.A. Cooper and R.T. DeCesar, "Missoula, Montana Source Apportionment Study", Final Report prepared for the Montana State Department of Health, September, 1980.

7. J.F. Kowalczyk and W.T. Green, "New Techniques for Identifying Ambient Air Impacts from Residential Wood Heating," Residential Solid Fuels, Environmental Impacts and Solutions, J.A. Cooper and D. Malek, Eds., Oregon Graduate Center, Beaverton, OR 1981.

8. Fine Particulates in Oregon's Air, Oregon Department of Environmental Quality, Air Quality Division, May, 1981.

9. J.H. Carlson, "Residential Wood Combustion in Missoula, Montana: An Overview of Its Air Pollution Contributions, Health Effects and Proposed Regulatory Solutions," Residential Solid Fuels, Environmental Impacts and Solutions, J.A. Cooper and D. Malek, Eds., Oregon Graduate Center, Beaverton, OR 1981.

10. J.E. Core, et al., "A Study of Residential Wood Combustion - Task 1, Ambient Air Quality Impact Analysis", Prepared for U.S. EPA, Region X, NEA, INC., April, 1982.

11. R.L. Gay and W.T. Greene, "Residential Wood Combustion Study - Task 3, Wood Fuel Use Projections," prepared for U.S. EPA, Region X, Del Green, Associates, Inc., April, 1982.

12. "Residential Wood Combustion Study - Task 2B, Household Information Survey," prepared for U.S. EPA, Region X, Del Green, Associates, Inc. February, 1982.

13. "Portland-Vancouver AQMA (Oregon Portion) State Implementation Plan for Total Suspended Particulate," State of Oregon Department of Environmental Quality, Air Quality Division, September, 1980.

14. J.G. Watson, J.C. Chow and J.J. Shaw, " Analysis of Measurements from the Inhalable Particulate Matter Sampling Network," U.S. EPA Contract No. 68-02-2542, July, 1981.

15. W.H. White and P.T. Roberts, "On the Nature of Visibility - Reducing Aerosols in the Los Angeles Air Basin," Atmos. Environ., 11:803 (1977).

16. R.J. Charleston, et al., "Monitoring of Atmospheric Aerosol Parameters With the Integrating Nephelometer," Journal of the Air Pollution Control Association, 19:937 (1969).

17. J.J. Shaw, J.J. Huntzicker, J.A. Cooper and J.G. Watson, "Sources of Visibility Degredation in Portland, Oregon," Proceedings of the 74th Annual Meeting, Air Pollution Control Association, 1981.

18. "Protecting Visibility: An EPA Report to Congress," U.S. EPA, 450/5-79-008, October, 1979.

19. "Development of a TSP State Implementation Plan for Medford," State of Oregon, Department of Environmental Quality, February 13, 1981.

20. R.L. Gay and W.T. Greene, "Residential Wood Combustion Study - Task 6, Control Strategy Analysis," Prepared for U.S. EPA, Region X, Del Green, Associates, May, 1982.

21. "Residential Wood Combustion Study - Task 4, Technical Analysis of Wood Stoves," Prepared for U.S. EPA, Region X, Del Green Associates, May, 1982.

22. Adams, D.F., Koppe, R.K. and Robinson, E., 1973, Air and Surface Measurements of Constituents of Prescribed Forest Slash Smoke, in: Proceedings of International Symposium on Air Quality and Smoke From Urban and Forest Fires, Fort Collins, Colorado, published by National Academy of Sciences, Washington, D.C., 1976, p. 105-120.

23. Adams, J.A.S., Lundell, L.L. and Mantovani, M.S.M., Wood Versus Fossil Fuel for Excess Carbon Dioxide (Letter): Science, v. 190, p. 1154.

24. Adams, J.A.S., Mantovani, M.S.M. and Lundell, L.L., 1977, Wood Versus Fossil Fuel as a Source of Excess Carbon Dioxide in the Atmosphere; a Preliminary Report: Science, v. 196, p. 54-56.

25. Aldrich, B.F. and Sanborn, C.R., 1979, Waterbury, Vermont: A Case Study of Residential Wood Burning, Montpelier, Vermont, Agency of Environmental Protection.

26. Allen, J.M., 1981, Control of Emissions from Residential Wood Burning by Combustion Modification, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 167-190.

27. Allwine, K.J., Jr., 1981, Assessment of the Long-Range Transport of Residential Woodstove Fine Particulate Emissions for Two Future United States Energy Scenarios, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

28. American Forestry Association, 1978, Wood for Energy: American Forests.

29. Anonymous, 1978, Can Air Pollutants Cause Chronic Lung Diseases?: Environ. Science Technology, v. 12, p. 1356.

30. Anonymous, 1978, Chemical Carcinogens: How Dangerous Are Low Doses?: Science, v. 202, p. 37-41.

31. Anonymous, 1978, Inhaled Particulates: Environmental Science Technology, v. 12, p. 1353.

32. Anonymous, 1979, Debate Continues Over Dow's Dioxin Theory: Chem. Eng. News 27.

33. Anonymous, 1979, Dow Dioxin Data Appear Reliable: Chem. Eng. News 19.

34. Anonymous, 1979, EPA Disputes Dow's Dioxin Theory: Chem. Eng. News 6.

35. Anonymous, 1980, The Lesson of Wood Burning?: Environmental Science & Technology, v. 14, p. 769-771.

36. Anonymous, 1980, Use of Wood for Energy Up in Pacific Northwest: Wood Energy Institute Reports, 3 pp.

37. Anonymous, 1981, CCEA Continues Study of Residential Wood Combustion: CCEA Conventional Combustion Environmental Assessment Program Report, v. 3, n. 1, 2 pp.

38. Anonymous, 1981, Device May Clean Up Wood Stoves, Oregonian, Feb. 10, 1981, p. 3M.

39. Anonymous, Biomass and Briquetting - An Inexhaustible Source of Cheap Energy for Quebec and Canada, 14 pp.

40. Anonymous, The Domestic Fire Testing Facility at the Department of Health's Environmental Laboratory, Auckland, 4 pp.

41. Anonymous, Wood Space Heating Emissions and Control Strategies in the Portland-Vancouver Air Quality Maintenace Area, 6 pp.

42. Aronow, W.S., 1981, Effects of 2% Venous Carboxyhemoglobin on Exercise-Induced Angina Pectoris, EPA-600/SI-81-012.

43. Ashe, W.F., 1952, United States Technical Conference on Air Pollution McCabe, L.C. (ed.), McGraw-Hill, New York, NY.

44. Auburn University, Mechanical Engineering Department, 1977, Woodburning Quarterly Report WB-1, 80 pp.

45. Auburn University, Mechanical Engineering Department, 1978, Safety, Efficiency, Output and Utility Testing, Product Development and Basic Research on Woodburning Units and Accessories at the AWL, 30 pp.

46. Auburn University, Mechanical Engineering Department, 1978, Woodburning Quarterly Report WB-2, 100 pp.

47. Auburn University, Mechanical Engineering Department, 1978, Woodburning Quarterly Report WB-3, 145 pp.

48. Auburn University, Mechanical Engineering Department, 1978, Woodburning Quarterly Report WB-4, v. I, 195 pp.

49. Auburn University, Mechanical Engineering Department, 1978, Woodburning Quarterly Report WB-4, v. II, 148 pp.

50. Auburn University, Mechanical Engineering Department, 1978, Woodburning Quarterly Report WB-4, v. III, 347 pp.

51. Auburn University, Mechanical Engineering Department, 1978, Woodburning Quarterly Report WB-5, 59 pp.

52. Auburn University, Mechanical Engineering Department, 1979, Creosote and Chimney Studies at the Auburn Woodburning Lab, 47 pp.

53. Auburn University, Mechanical Engineering Department, 1979, Efficiency and Heat Output Measurements for Residential Wood Heating Appliances, 92 pp.

54. Auburn University, Mechanical Engineering Department, 1979, Improving the Efficiency, Safety and Utility of Woodburning Units - Major Accomplishments, 33 pp.

55. Auburn University, Mechanical Engineering Department, 1979, Independence, Economic Advantage, Hazard, and Confusion From Wood Energy as an Alternative Resource, 16 pp.

56. Auburn University, Mechanical Engineering Department, 1979, Measuring the Efficiency and Heat Output of Residential Wood Heating Appliances, 24 pp.

57. Auburn University, Mechanical Engineering Department, 1979, Results of Six Tests to Assess the Accuracy of the Flue Loss Method Versus the Calorimeter Test Procedure, 24 pp.

58. Auburn University, Mechanical Engineering Department, 1979, Special Creosote Report, 144 pp.

59. Auburn University, Mechanical Engineering Department, 1979, Standard for Rating Wood Fired, Closed-Combustion Chamber Heating Appliances, 26 pp.

60. Auburn University, Mechanical Engineering Department, 1979, Studies of Creosote and Chimneys at the AWL, 76 pp.

61. Auburn University, Mechanical Engineering Department, 1979, Wood Heating - Can It Work?, 11 pp.

62. Auburn University, Mechanical Engineering Department, 1979, Woodburning Quarterly Report WB-6, 121 pp.

63. Auburn University, Mechanical Engineering Department, 1979, Woodburning Quarterly Report WB-7, 44 pp.

64. Auburn University, Mechanical Engineering Department, 1979, Woodburning Shortcourse Booklet.

65. Auburn University, Mechanical Engineering Department, 1979, Woodburning Stove Efficiency Data (Condensed Version of WB-4, v. III), 20 pp.

66. Barnett, S.G., 1981, The Effects of Woodstove Design on Condensable Particulate Emissions and Creosote Formation Rate, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

67. Barnett, S.G., 1981, The Effects of Woodstove Design on Condensable Particulate Emissions, In-Home Delivered Efficiency, and Creosote Formation Rate, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 268-269.

68. Baum, F., 1974, Measures for the Reduction of Emissions from Wood-Fired Furnaces: Gesundheits-Ingenieur, 95, p. 362-363.

69. Beall, S.E. et. al, 1974, Assessment of Environmental Impact of Alternative Energy Sources, Oak Ridge National Laboratory, Tennessee, Report No. ORNL-5024, 134 pp.

70. Bendersky, C., 1981, Results of the DOE Think Shop on Residential Wood Combustion, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 275.

71. Bergvall, J.A., Bullington, D.C. and Gee, L., 1979, Wood Waste for Energy Study, Final Literature Review, State of Washington, Department of Natural Resources, 265 pp.

72. Bergvall, J.A., Bullington, D.C., Gee, L. and Koss, W., 1978, Wood Waste for Energy Study, Inventory Assessment and Economic Analysis, State of Washington, Department of Natural Resources, 216 pp.

73. Bergvall, J.A., Gee, L. and Koss, W., 1979, Wood Waste for Energy Study, Executive Summary, State of Wasnington, Department of Natural Resources, 16 pp.

74. Berk, J.V., Young, R.A., Brown, S.R. and Hollowell, C.D., 1981, Impact of Energy-Conserving Retrofits on Indoor Air Quality in Residential Housing, in: 74th Annual Meeting of the Air Pollution Control Association, Philadelphia, Pennsylvania, 27 pp.

75. Blanchet, M.A. and Sanborn, C., 1981, Particulate Emissions from Residential Wood Combustion in Vermont, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

76. Booz, Allen and Hamilton, 1979, Assessment of Proposed Federal Tax Credits for Residential Wood Burning Equipment, report for the U.S. Department of Energy, Report No. SAN-1693-1, 212 pp.

77. Bosserman, P.B., Tombleson, B. and Kowalczyk, J., 1981, Particulate Emissions from New, Low Emission Wood Stove Designs Measured by EPA Method V, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A. (ed.), Portland, Oregon.

78. Bohac, C.E., Duncan, J.R. and Beeman, L.E., 1981, Residential Wood Combustion Issues for the Tennessee Valley, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 274.

79. Bohac, C.E. and Hickey, H.R., 1980, Environmental Considerations of Alternative Uses of Wood for Energy, Tennessee Valley Authority, Office of Natural Resources, Chattanooga.

80. Braeten, R., Sellers, T., Prokopuk, R., Lee, S.W., Thomas, R.S. and Lao, R.C., 1981, Investigations of Priority Organic Pollutants and Particulate Organic Matter Emissions from Wood-Burning Stoves, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

81. Brandon, R.J., 1981, An Assessment of the Efficiency and Emissions of Ten Wood Fired Furnaces, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 267.

82. Brimblecombe, P., 1975, Industrial Air Pollution in Thirteenth Century Britain: Weather 30, p. 388-396.

83. Brimblecombe, P., Attitudes and Responses Towards Air Pollution in Medieval England: Journal of the Air Pollution Control Association, v. 26, No. 10, p. 941-945.

84. Brimblecombe, P. and Ogden, C., 1977, Air Pollution in Art and Literature, Weather 32, p. 285-291.

85. Brimblecombe, P., 1978, Air Pollution in Industrializing England: Journal of the Air Pollution Control Association, v. 28, No. 2, p. 115-118.

86. Brimblecombe, P., 1981, Environmental Impact of Fuel Changes in Early London, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

87. Brimblecombe, P. and Wigley, T.M., 1978, Early Observations of London's Urban Plume: Weather 33, p. 215-220.

88. Buser, H.R., Bosshardt, H.P. and Rappe, C., 1978, Identification of Polychlorinated Dibenzo-o-dioxin Isomers found in Fly Ash: Chemosphere (No.2) p. 165.

89. Butcher, S.S., 1978, The Air Pollution Potential of Small Wood Stoves, in: Proceedings of Wood Heating Seminar 3, Madison, Wisconsin, p. 1-12.

90. Butcher, S.S., 1978, The Impact of Residential Heating by Wood Stoves on Ambient Air Quality, Report to the Maine Department of Environmental Protection.

91. Butcher, S.S. and Buckley, D.I., 1977, Preliminary Study of Particulate Emissions from Small Wood Stoves: Journal of the Air Pollution Control Association, 27, p. 346-348.

92. Butcher, S.S. and Ellenbecker, M.J., 1981, Particulate Emission Factors for Small Wood and Coal Stoves, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

93. Butcher, S.S. and Sorenson, E.M., 1979, Study of Wood Stove Particulate Emission: Journal of the Air Pollution Control Association, 29, p. 724-728.

94. Butler, J.D. and Crossley, P., 1979, An Appraisal of Relative Airborne Sub-urban Concentrations of Polycyclic Aromatic Hydrocarbons Monitored Indoors and Outdoors: The Science of the Total Environment, p. 53-58.

95. Carlson, J.H., 1981, Wood-Burning in Missoula, Montana, Air Quality, Health Effects, and Possible Solutions, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

96. Carlsson, S., 1981, Residential Wood Combustion in Sweden-Environmental Aspects and Regulations, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

97. Carnow, B.W., 1978, The 'Urban Factor' and Lung Cancer: Cigarette Smoking or Air Pollution?: Environmental Health Perspectives, v. 22, p. 17.

98. Carnow, B.W. and Meier, P., 1973, Air Pollution and Pulmonary Cancer: Arch. Environmental Health, v. 27, p. 207.

99. Cavanaugh, W., 1980, Vegan Invents 'Scrubber' To Help Fight Pollution, Las Vegas Sun, October 12, 1980, p. 14.

100. Cawthron Technical Group, 1981, Efficiency Testing of Domestic Space Heaters, Nelson, New Zealand, 4 pp.

101. Chlorinated Dioxin Task Force, The Michigan Division, Dow Chemical, 1978, The Trace Chemistries of Fire-A Source of and Routes for the Entry of Chlorinated Dioxins into the Environment.

102. Clayton, L., et al., 1968, Emissions from Residential Type Fireplaces, San Francisco, Bay Area Air Pollution Control District, 68 pp.

103. Clean Air Council, Requirements for the Design and Testing of Solid Fuel Burning Domestic Heating Appliances, Wellington, New Zealand, 6 pp.

104. Collom, R.H., Jr., 1973, Georgia's Open Burning Regulations, in: Proceedings of International Symposium on Air Quality and Smoke From Urban and Forest Fires, Fort Collins, Colorado, published by National Academy of Sciences, Washington, D.C., 1976, p. 198-205.

105. Colome, S.D., Irvine, C.A. and SPengler, J.D., 1981, Residential Indoor and Matched Outdoor Measurements of Fine Particulate Trace Elements, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

106. Cooke, W.M., Allen, J.M. and Hall, R.E., 1981, Characterization of Emissions from Residential Wood Combustion Sources, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

107. Cooper, J.A., 1979, Medford Aerosol Characterization Study (MACS), Report to Oregon Department of Environmental Quality.

108. Cooper, J.A., 1980, Environmental Impact of Residential Wood Combustion Emissions And Its Implications, in: Proceedings of Wood Heating Seminar 6, Atlanta, Georgia, p. 26-55.

109. Cooper, J.A., 1981, Chemical and Physical Methods of Apportioning the Contributions of Emissions from Residential Solid Fuels to Reductions in Air Quality, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

110. Cooper, J.A., submitted for publication, Assessment of Contemporary Carbon Combustion Source Contributions to Urban Air Particulate Levels Using Carbon-14 Measurements.

111. Cooper, J.A., Currie, L.A., and Klouda, G.A., 1979, Evaluation of Carbon-14 as a Unique Tracer to Determine the Maximum Impact of Contemporary Carbon Sources of Atmospheric Particulates to the Portland and Eugene Airsheds, Final Report to the Oregon Department of Environmental Quality.

112. Cooper, J.A., Currie, L.A. and Klouda, G.A., submitted for publication, Application of Carbon-14 Measurements to Impact Assessment of Contemporary Carbon Sources on Urban Air Quality.

113. Cooper, J.A. and Watson, J.G., 1979, Portland Aerosol Characterization Study (PACS): Application of Chemical Mass Balance Methods to the Identification of Major Aerosol Sources in the Portland Airshed, Prepared for Portland Air Quality Maintenance Area Advisory Committee and Oregon Department of Environmental Quality, 67 pp.

114. Cooper, J.A., Watson, J.G. and Huntzicker, J.J., 1979, Summary of the Portland Aerosol Characterization Study (PACS), in: Air Pollution Control Association, Cincinnati.

115. Cooper, R.W., 1973, Trade-Offs Between Smoke from Wild and Prescribed Forest Fires, in: Proceedings of International Symposium on Air Quality and Smoke From Urban and Forest Fires, Fort Collins, Colorado, published by National Academy of Sciences, Washington, D.C., 1976, p. 19-26.

116. Corrin, M.L., 1973, Physics of Smoke Formation, in: Proceedings of International Symposium on Air Quality and Smoke From Urban and Forest Fires, Fort Collins, Colorado, published by National Academy of Sciences, Washington, D.C., 1976, p. 90-100.

117. Craig, L.S., 1979, Residential Wood Survey, memo containing the results of a state and area wood use survey conducted by GMA Research Corp, in the winter of 1979.

118. Cramer, O.P. and Pickford, S.G., 1973, in: Proceedings of International Symposium on Air Quality and Smoke From Urban and Forest Fires, Fort Collins, Colorado, published by National Academy of Sciences, Washington, D.C., 1976, p. 231-240.

119. Crossley, F.R.E., 1980, Wood Chips - An Alternative Heating Fuel: Mechanical Engineering, p. 36-43.

120. Currie, L.A., and Klouda, G.A., 1981, Radiocarbon: Nature's Tracer for Carbonaceous Pollutants, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

121. Curtis, C.J., 1980, Coping With Creosote, in: Proceedings of Wood Heating Seminar 6, Atlanta, Georgia, p. 56-68.

122. D'Alessio, G.J. and Kawaoka, K.E., 1980, Health Effects of Residential Wood Combustion: Survey of Knowledge and Research, U.S. Department of Energy, Office of Technology Impacts, Technology Assessments Division, draft, 19 pp.

123. Dalton, M.M., Durgin, O.B., Herrington, J.H. and Andrews, R.A., 1977, Household Fuel Wood Use and Procurement in New Hampshire, University of New Hampshire research report Number 59.

124. Dalton, M.M., Herrington, J.H., Durgin, O.B. and Andrews, R.A., 1977, Household Fuel Wood Use and Procurement in New Hampshire, Research Report No. 59, 24 pp.

125. Darley, E.F., Lerman, S., Miller, G.E. and Thompson, J.F., 1973, Laboratory Testing for Gaseous and Particulate Pollutants from Forest and Agricultural Fuels, in: Proceedings of International Symposium on Air Quality and Smoke From Urban and Forest Fires, Fort Collins, Colorado, published by National Academy of Sciences, Washington, D.C., 1976, p. 78-89.

126. Davidovits, P. and Faist, M.B., 1981, Formation of Submicron Ash Particles in Coal Combustion, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

127. DeAngelis, D.G., 1978, Source Assessment: Residential Combustion of Wood, report to the U.S. Environmental Protection Agency under Contract Number 68-02-1874.

128. DeAngelis, D.G., Peters, J.A., Ruffin, D.S., and Hughes, T.W., Air Emissions from Combustion of Wood in Space-Heating Stoves and Fireplaces, 14 pp.

129. DeAngelis, D.G., Peters, J.A., Ruffin and Huges, T.W., unpublished manuscript, Combustion of Wood in Space-Heating Stoves and Fireplaces, 14 pp.

130. DeAngelis, D.G., and Reznik, R.B., 1978, Source Assessment: Coal-Fired Residential Combustion Equipment Field Tests, June 1977, report for U.S. Environmental Protection Agency, Report No. EPA-600/2-78-004, 83 pp.

131. DeAngelis, D.G., Ruffin, D.S., Peters, J.A., and Reznik, R.B., 1980, Source Assessment: Residential Combustion of Wood, Prepared by Monsanto Research Corporation for U.S. Environmental Protection Agency, Report No. 600/2-80-042B, 91 pp.

132. DeAngelis, D.G., Ruffin, D.S. and Reznik, R.B., 1979, Source Assessment: Wood-Fired Residential Combustion Equipment Field Tests, U.S. Environmental Protection Agency report number MCR-DA-EPA-600/2-79-019.

133. DeAngelis, D.G., Ruffin, D.S., and Reznik, R.B., 1980, Preliminary Characterization of Emissions from Wood-Fired Residential Combustion Equipment, Prepared by Monsanto Research Corporation for U.S. Environmental Protection Agency, Report No. EPA-600/7-80-040, 146 pp.

134. Deats, R.A., 1981, Domestic Hot Water and Hydronics Installations, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 191-220.

135. DeCesar, R.T. and Cooper, J.A., 1981, The Quantitative Impact of Residential Wood Combustion and Other Vegetative Burning Sources on the Air Quality in Medford, Oregon, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

136. Dickinson, R., 1970, Measurements of Domestic Smoke Emission and Their Application to Clean Air Legislation: Journal of the Institute of Fuel, 43, p. 75-81.

137. Doerr, R.C., Wasserman, A.E. and Fiddler, W., 1966, Composition of Hickory Sawdust Smoke: Low-Boiling Constituents: Journal of Agricultural and Food Chemistry, 14, p. 662-665.

138. Duncan, J.R., et al., 1979, How Clean is Our Air? An Assessment of Air Quality in the Tennessee Valley, Division of Natural Resources Services, Air Quality Branch, Tennessee Valley Authority, Office of Natural Resources, Chattanooga, 32 pp.

139. Duncan, P.E., Kieron, M.M. and Schierbach, M.P., 1979, Air Quality Impact Potential From Residential Wood-Burning Stoves, report for the Tennessee Valley Authority, 16 pp.

140. Duncan, J.R., Morkin, K.M. and Schmierbach, M.P., 1980, Air Quality Impact Potential from Residential Wood-Burning Stoves, in: 73rd Annual Meeting of the Air Pollution Control Association, Montreal, Quebec, 15 pp.

141. Earl, D.E., 1974, Charcoal, Food and Agriculture Organization of the United Nations, 97 pp.

142. Earl, W.L., 1981, An Investigation of Wood Pyrolysis and Smoldering Using Solid State ^{13}C Nuclear Magnetic Resonance, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

143. Edgerton, S., 1981, Assessing the Contribution of Residential Wood Combustion to Ambient Pollutant Concentration: A Surrogate Real-Time Method, 9 pp.

144. Ember, L.R., 1978, Can Air Pollutants Cause Chronic Lung Diseases?: Environmental Science & Technology, v. 12, no. 13, p. 1356-1359.

145. Esposito, M.P. and Watkins, D.R., 1980, Airborne Dioxins: The Problem in Review, in: 73rd Annual Meeting of the Air Pollution Control Association, Montreal, Quebec, 15 pp.

146. Fiddler, W.R., Wasserman, A.E. and Salary, 1966, Composition of Hickory Sawdust Smoke; Furons and Phenols: Journal of Agricultural and Food Chemistry, 14, p. 659, 662.

147. Flesh, R.D., Riha, M.L. and Duffee, R.A., 1981, Odor Acceptability in the Indoor Environment, in: 74th Annual Meeting of the Air Pollution Control Association, Philadelphia, Pennsylvania, 16 pp.

148. Garrett, L.D., 1978, The Economic Implications of Using Wood Space Heaters for Home Comfort Heat, in: Proceedings of Wood Heating Seminar 3, Madison, Wisconsin, p. 390-415.

149. Gay, R.L. and Cooper, J.A., 1981, Particulate Air Quality Impact of Residential Wood Combustion on Three Cities in the Pacific Northwest, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

150. Gay, R.L., Kowalczyk, J.F. and Greene, W.T., 1981, New Techniques for Identifying Ambient Air Impacts from Residential Wood Heating, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

151. Geurin, M.R., Epler, J.L., Griest, W.H., Clark, B.R. and Rao, T.K., 1978, Polycyclic Aromatic Hydrocarbons from Fossil Fuel Conversion Processes: Carcinogenesis, v. 3, p. 21-33.

152. Giammar, R.D., Hopper, D.R., Radhakrishan, E. and Webb, P.R., 1980, Limestone/Coal Fuel Pellet - A Viable Method to Control SO_2 Emissions from Industrial Boilers, in: 73rd Annual Meeting of the Air Pollution Control Association, Montreal, Quebec.

153. Greene, W.T., 1980, Wood Space Heating Emissions and Cover Strategies in the Portland-Vancouver Air Quality Maintenance Area, Portland, Oregon Department of Environmental Quality.

154. Greene, W.T. and Tombleson, B.J., 1981, Institutional and Regulatory Approaches to Control Residential Wood Burning Emissions, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

155. Greene, W.T. and Tombleson, B.J., 1981, Institutional and Regulatory Approaches To Control Residential Wood Burning Emissions, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 271.

156. Griest, W.H., Tomkins, B.A., Epler, J.L. and Rao, T.K., 1979, Characterization of Multialkylated Polycyclic Aromatic Hydrocarbons in Energy-Related Materials, in: Polynuclear Aromatic Hydrocarbons Third International Symposium on Chemistry and Biology - Carcinogenesis and Mutagenesis, p. 395-409.

157. Grimsrud, D.T., Sherman, M.H., Blomsterberg, A.K. and Rosenfeld, A.H., 1979, Infiltration and Air Leakage Comparisons: Conventional and Energy-Efficient Housing Designs, Lawrence Berkeley Laboratory, Report No. LBL-9157, 22 pp.

158. Grimsrud, D.T., Sherman, M.H., Janssen, J.E., Pearman, A.N. and Harrje, D.T., 1979, An Intercomparison of Tracer Gases Used for Air Infiltration Measurements, Lawrence Berkeley Laboratory, Report No. LBL-8394, 13 pp.

159. Grimsrud, D.T., Sonderegger, R.C., Sherman, M.H., Diamond, R.C. and Blomsterberg, A., unpublished manuscript, Calculating Infiltration: Implications for a Construction Quality Standard, Lawrence Berkeley Laboratory, Draft No. LBL 9416, 41 pp.

160. Hall, E.H., et al., 1976, Comparison of Fossil and Wood Fuels, Prepared by Battelle Columbus Labs for U.S. Environmental Protection Agency, Report No. EPA-600/2-76-056 (NTIS Accession No. PB-251 622), 254 pp.

161. Hall, J.A., 1972, Forest Fuels, Prescribed Fire and Air Quality, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 44 pp.

162. Hall, R.E., 1981, Emissions Assessment of a Standard Wood Stove Comparing Stack versus Dilution Tunnel Sampling, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 270.

163. Hall, R.E., 1981, E.P.A.'s Research Program for Controlling Residential Wood Combustion Emissions, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 44-63.

164. Hall, R.E. and DeAngelis, D.G., 1980, EPA's Research Program for Controlling Residential Wood Combustion Emissions: Journal of the Air Pollution Control Association.

165. Hand, A.J., 1976, Wood as Fuel: Popular Science, p. 104-107.

166. Hand, O.F., 1980, What's Wrong with Wood Smoke?: The National Wood Stove and Fireplace Journal, v. 2.

167. Hangebrauck, R.P. and Von Lehmden, D.J., 1964, Emissions of Polynuclear Hydrocarbons and other Pollutants from Heat-generation and Incineration Processes: JAPCA v. 14, p. 267.

168. Hansen, H.J., 1980, Fuelwood Facts, circular 1023, 4 pp.

169. Harkness, J., 1980, Stove Emission Program at the Argonne National Laboratory, in: Proceedings of Wood Heating Seminar 6, Atlanta, Georgia, p. 108-109.

170. Harper, J.P., 1981, Residential Wood Heating Efficiency and Emissions - An Overview, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 276.

171. Hatch, C.L., Odell, F.G. and Riley, H.L., 1976, Medford-Ashland Air Quality Maintenance Area Analysis.

172. Hatchard, R.E. and Day, T.E., 1979, letter report on survey of Portland AQMA to Peter B. Bosserman of the Oregon Department of Environmental Quality. Personal communication with Bill Green, Oregon Dept. of Environmental Quality, Jan. 15, 1980.

173. Hausmann, F., Briquetting Wood Waste by the Hausmann Method, Fred Hausmann Ltd., Basel/Switzerland, 20 pp.

174. Hayden, A.C.S., 1978, Efficiency of Wood-Fired Appliances, Energy, Mines and Resources Canada, Report No. ERP/ERL 78-82 (TR) (OP), 26 pp.

175. Hayden, A.C.S. and Braaten, R.W., 1980, Performance of Domestic Wood-Fired Appliances, in: 73rd Annual Meeting of the Air Pollution Control Association, Montreal, Quebec, 13 pp.

176. Hayden, A.C.S. and Braaten, R.W., 1981, Effective Efficiency of Various Wood Heating Systems, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

177. Hayden, A.C.S. and Braaten, R.W., 1981, Efficient Wood Stove Design and Performance, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 16-43.

178. Hewett, C.E. and High, C., 1979, Environmental Aspects of Wood Energy Conversion, Dartmouth College, Resource Policy Center, Hanover, New Hampshire.

179. Hill, R.C., 1979, Design, Construction and Performance of Stick-Wood Fired Furnace for Residential and Small Commercial Application, report for U.S. Department of Energy, 26 pp.

180. Hirose, K. and Fujiwara, T., 1974, A Study of Dust Abatement by Combustion in: Memoirs of the School of Engineering, Okayama University, 9.

181. Hites, R.A., LaFlamme, R.E. and Windsor, J.G., 1980, Polycyclic Aromatic Hydrocarbons in Marine/Aquatic Sediments: Their Ubiquity: Advances in Chemistry Series, No. 185, p. 290-311.

182. Hoffman, D. and Wynder, E.L., 1976, Environmental Respiratory Carcinogens: Chemical Carcinogens, Searle, C.E. (ed.), American Chemical Society, p. 324.

183. Holdren, J.P., Morris, G. and Mintzer, I., 1980, Environmental Aspects of Renewable Energy Sources, 50 pp.

184. Hone, R.W., 1979, Reduction of Creosote in Wood Burning Stoves, in: Proceedings of Wood Heating Seminar 4, Portland, Oregon, p. 195-227.

185. Hornig, J.F., Soderberg, R.H. and Larsen, D., 1981, Ambient Air Assessment in a Rural New England Village Where Wood is the Dominant Fuel, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 140-153.

186. Hornig, J.F., Soderberg, R.H. and Parravano, C., 1981, Ambient Air Assessment in Rural Village and Small Town Locations in New Hampshire Where Wood is an Important Fuel, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

187. Hruza, D.E., Van Praag, M. and Heinsohn, H., Jr., 1974, Isolation and Identification of the Components of the T of Hickory Wood Smoke: Journal of Agricultural and Food Chemistry, 22, p. 123-126.

188. Hubble, B.R. and Harkness, J.B.L., 1981, Results of Laboratory Tests on Wood Stove Efficiency and Emissions, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 277.

189. Hubble, B.R., Harkness, J.B.L., Gerbert, E., Stetter, J.R., and Flotard, R.D., 1981, Experimental Measurements of Residential Wood Burning Stove Emissions, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A. (ed.), Portland, Oregon.

190. Imhoff, R.E., Manning, J.A., Cooke, W.M. and Hayes, T.L., 1981, A Study of the Ambient Impact of Residential Wood Combustion in Petersville, Alabama, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

191. Island Energy Associates, 1980, Wood Fired Residential Heating Demonstration: Final Report for The Institute of Man and Resources, 7. pp.

192. Jaasma, D.R., 1981, Catalysis of Woodstove Effluet, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

193. Jaasma, D.R., 1981, Measurements of Chemical Changes Due to Catalysis of Woodstove Effluent, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 221-230.

194. Jacobs, P. and Bunch, S., 1981, Health Costs Due to Residential Solid Fuel Pollution in the United States, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

195. Jahnsen, V.J., 1961, The Chemical Composition of Hardwood Smoke: Ph.D. Thesis, Purdue University.

196. Jansma, D.R. and Metcalfe, C.I., 1980, Real-Time Measurements of Emissions from an Airtight Woodstove, in: Spring Meeting of the Central States Section of the Combustion Institute, Baton Rouge, Louisiana.

197. Johnson, K.G., Gideon, R. and Loftsgaarden, D., 1981, Montana Air Pollution Study: Synopsis of Polmonary Function Studies, in: 74th Annual Meeting of the Air Pollution Control Association, Philadelphia, Pennsylvania, 16 pp.

198. Jorstad, R.K., 1979, The Relationship Between Different Levels of Moisture Content in Red Oak and the Resulting Creosote Buildup in the Chimney During the Burning Process in an Airtight Furnace: M.S. thesis, University of Wisconsin.

199. Katzer, G.R., 1979, Stoking the New Generation Wood-Burners: The New Zealand Energy Journal, p. 141-143.

200. Kelsey, M.I., Kraybille, H.F., Helmes, C.T. and Sigman, C.C., 1981, A Data Base of Organic Pollutants That Have Been Evaluated for Carcinogenicity and Mutagenicity, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

201. Kerr, R.A., 1977, Carbon Dioxide and Climate: Carbon Budget Still Unbalanced: Science, 197, p. 1352-1353.

202. Kipling, M.D., 1976, Soots, Tars and Oils as Causes of Occupational Cancer: Chemical Carcinogens, American Chemical Society, 315 pp.

203. Klein, E.L., 1979, Wood - Its Role as an Alternative Fuel, in: Proceedings of Wood Heating Seminar 5, St. Louis, Missouri, p. 27-46.

204. Knight, C.V. and Harper, J.P., 1981, Measurement of Wood Heater Thermal and Emissions Performance, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

205. Knight, D.K., 1981, Wood Heat Emission Workshop, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 73-86.

206. Kosel, P.H., 1981, Pollution and Fireplaces in California, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 242-251.

207. Kosel, P.H., 1981, Emissions from Residential Fireplaces, Sacramento, California Air Resources Board.

208. Kraybill, H.F., 1977, Conceptual Appraoches to the Assessment of Non-occupational Environmental Cancer: Environmental Cancer, Kraybill, H.F. and Mehlman, M.A., (ed.), p. 27.

209. Krishnan, S., Kaden, D.A., Thilly, W.G. and Hites, R.A., 1979, Cyanoarenes in Soot: Synthesis and Mutagenicity of Cyanoacenaphthylenes: Environmental Science & Technology, v. 13, p. 1532.

210. Landry, B.A. and Sherman, R.A., 1950, The Development of a Design of Smokeless Stove for Bituminous Coal, in: Transactions of the American Society of Mechanical Engineers, 72, p. 9-17.

211. Larsen, R.I., 1970, Relating Air Pollutant Effects to Concentration and Control: JAPCA, v. 20, p. 214.

212. Lawther, P.L., 1981, Historic Changes in Air Pollution in Great Britain, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

213. Lee, M.L., Prado, G.P., Howard, J.B., and Hites, R.A., 1977, Source Identification of Urban Airborne Polycyclic Aromatic Hydrocarbons by Gas Chromatographic Mass Spectrometry and High Resolution Mass Spectrometry: Biomedical Mass Spectrometry, v. 4, p. 182.

214. Lewtas, J., 1981, Comparison of the Mutagenic and Potentially Carcinogenic Activity of Particle Bound Organics from Wood Stoves, Residential Oil Furnaces, and Other Combustion Sources, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

215. Lim, K.J. and Lips, H.I., 1981, Overview of Emissions from Wood Combustion, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 273.

216. Lindstrom, O., 1981, Gasification Combustion of Wood, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

217. Lipfert, F.W., Graves, W.L. and Carney, T., 1981, Utilization and Air Quality Impact of Residential Wood Fuel Use in the Northeast, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

218. Logan, W.P.D., 1953, Mortality in the London Fog Incident: Lancet, v. 1, p. 336.

219. Lustre, A.O. and Issenberg, P., 1969, Volatile Components of Hardwood Sawdust Smoke-Components of Phenolic Fraction: Journal of Agricultural and Food Chemistry, 17, p. 1387-1393.

220. Lyon, L.H., 1980, Pollutant Cloud Shrouds Valley, Las Vegas Sun, October 11, 1980, p. 9.

221. Machlin, P.R., 1981, Woodburning in the Environmental Protection Agency Region VIII States/Issues and Options for Control, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

222. Mahan, B.L., 1981, The Relationship Between Heating with Wood and Air Pollution: An Economic Case Study, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

223. Martel, C., Jr., 1981, (ed.), 1981, Woodstove, Coalstove, Fireplace & Equipment Directory, Energy Communications Press, Inc., Manchester, New Hampshire, 376 pp.

224. Martin, W., 1981, European Experience and Activities in Assessing the Environmental Impacts from Wood Combustion, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

225. Martin, W. and Morris, C.A., 1979, Assessment of Environmental Impacts of Increased Wood Combustion in Western North Carolina, Raleigh, North Carolina Division of Energy, 60 pp. plus appendices.

226. Martin, W. and Morris, C.A., 1981, Environmental Impacts from Wood Combustion, paper presented at: IGT's Fifth Annual Meeting on Energy From Biomass and Wastes, Lake Buena Vista, FL, 37 pp.

227. Maughan, D., 1981, Comparison of Impact Assessment Methods for Residential Wood Combustion in Missoula, Montana, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

228. Maxwell, T., 1979, Ongoing Report: Chimney and Creosote Problems, in: Wood Heating Seminar V, St. Louis.

229. Maxwell, T.T., Dyer, D.F. and Maples, G., 1979, Measuring the Efficiency and Heat Output of Residential Wood Heating Appliances, in: Proceedings of Wood Heating Seminar 4, Portland, Oregon, p. 105-187.

230. Maxwell, T.T., Dyer, D.F., and Maples G., 1979, Studies of Creosote and Chimneys at the Auburn Wood Burning Laboratory, in: Proceedings of Wood Heating Seminar 5, St. Louis, Missouri, p. 118-198.

231. Maxwell, T.T., Dyer, D.F., and Maples, G., 1980, Efficiency and Heat Output Measurement for Residential Wood Heating Appliances, in: Proceedings of Wood Heating Seminar 6, Atlanta, Georgia, p. 119-228.

232. McMahon, C.K. and Tsonkalas, S.N., 1978, Polynuclear Aromatic Hydrocarbons in Forest Fire Smoke: Carcinogenesis, v. 3: Polynuclear Aromatic Hydrocarbons, Jones, P.W. and Freudenthal, R.I., (ed.), p. 61.

233. Meyer, H.R., 1981, The Contribution of Residential Wood Combustion Emissions to Local Airshed Concentrations, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

234. Miller, D.P., 1981, A Study of Occupant Exposure to Particulates and Gases from Woodstoves in Homes, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

235. Miller, J.D., Schneider, M.H. and Whitney, N.J., Fungi on Fuel Wood Chips in a Home, 12 pp.

236. Milliken, J.O., 1979, Airborne Emissions from Wood Combustion, in: Wood Heating Seminar IV, Portland, Oregon, Wood Energy Institute.

237. Milliken, J.O., 1979, Airborne Emissions Resulting from Combustion of Wood, in: Proceedings of Wood Heating Seminar 4, Portland, Oregon. p. 271-285.

238. Milliken, J.O., 1979, Environmental Assessment of Wood Combustion Process-Current EPA Programs, in: Wood Heating Seminar V, St. Louis.

239. Milliken, J.O., 1979, Environmental Assessment of Wood Combustion Processes, in: Proceedings of Wood Heating Seminar 5, St. Louis, Missouri, p. 47-53.

240. Milliken, J.O., 1979, Wood Combustion Commercialization Program: Environmental Aspects, U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina.

241. Morgan, S., 1979, Expanding the Utilization of Wood to Alleviate New England's Home Heating Oil Crisis This Winter, in: Proceedings of Wood Heating Seminar 5, St. Louis, Missouri, p. 54-81.

242. Morris, G., 1981, Health Effects of Residential Wood Combustion- The Implications of Environmental Stochasticity, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

243. Mors, T.A., Blair, T.T. and Cole, R.H., 1981, Regulatory Options for Controlling Emissions from Combustion of Wood in Residential Applications, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

244. Moschandreas, D.J. and Berg, D.R., 1981, The Effects of Woodburning on Indoor Pollutant Concentrations, in: 74th Annual Meeting of the Air Pollution Control Association, Philadelphia, Pennsylvania, 13 pp.

245. Muhlbaier, J.L., 1981, A Characterization of Emissions from Residential Wood-burning Fireplaces, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

246. Murphy, B., 1980, A Smoke-Eater for a Wood Stove: Mechanics Illustrated, Nov., p. 128.

247. Murphy, D.J., Buchan, R.M. and Fox, D.G., 1981, Ambient Particulate and Benzo (α) Pyrene Concentrations in a Mountain Resort Community From Residential Wood Combustion, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

248. National Academy of Sciences, 1972, Particulate Polycyclic Organic Matter, p. 234.

249. National Academy of Sciences, 1980, Energy Choices in a Democratic Society, International Standard Book Number 0-309-03045-5, report of the Consumption, Location, and Occupational Patterns Resource Group Synthesis Panel to the Committee on Nuclear and Alternative Energy Systems, Washington, D.C., 136 pp.

250. National Academy Press, 1980, Energy and the Fate of Ecosystems, International Standard Book No. 0-309-03098-6, report of the Ecosystem Impacts Resource Group Risk and Impact Panel to the Committee on Nuclear and Alternative Energy Systems, Washington, D.C., 399 pp.

251. National Research Council, 1979, Alternative Energy Demand Futures To 2010, International Standard Book No. 0-309-02939-2, report of the Demand and Conservation Panel to the Committee on Nuclear and Alternative Energy Systems, Washington, D.C., 281 pp.

252. National Society for Clean Air, 1964, United Kingdom Smoke Control Areas under the Clean Air Acts.

253. Neilson, R.C., 1973, Laws, Standards, and Regulations for Smoke Abatement in Montana, in: Proceedings of International Symposium on Air Quality and Smoke From Urban and Forest Fires, Fort Collins, Colorado, published by National Academy of Sciences, Washington, D.C., 1976, p. 180-182.

254. New York Times, May 23, 1979.

255. Nunn, A.B., Preliminary Compilation of Data for Emissions from Wood-Fired Boilers, Prepared by TRW for U.S. Environmental Protection Agency.

256. Olie, K., Vermeulen, P.L., and Huntzicker, O., 1977, Chlorodibenzop-dioxins and Chlorodibenzofurnas are Trace Components in Fly Ash and Flue Gas of Some Municipal Incinerators in the Netherlands: Chemosphere (No. 8), p. 455.

257. OMNI Environmental Services, 1981, Emission Test Report on Four Selected Wood Burning Home Heating Devices, report for Oregon Department of Energy, 25 pp.

258. Oregon Department of Environmental Quality, 1980, Interpretation fo Wood Stove Emission Testing Conducted in Oregon in 1980, 5 pp.

259. Oregonian p. 3m, Nov. 12, 1978.

260. Osborne, M.C., 1981, An Overview of R&D Programs Being Coordinated by the Inter-Governmental Wood Combustion Research Group, in: 74th Annual Meeting of the Air Pollution Control Association, Philadelphia, Pennsylvania, 15 pp.

261. Osborne, M.C., 1981, The Inter-Government Research and Development Program for Residential Wood Combustion, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

262. Otis, T., 1977, Wood Burning and Particulate Air Pollution in the Missoula Valley, Missoula City-County Health Department, Air Pollution Control Division, Missoula, Montana, 27 pp.

263. Patterson, H.M., 1973, Laws, Standards, and Regulations for Smoke Abatement in Oregon, in: Proceedings of International Symposium on Air Quality and Smoke From Urban and Forest Fires, Fort Collins, Colorado, published by National Academy of Sciences, Washington, D.C., 1976, p. 183-197.

264. Pedco-Environmental, Inc. (Kansas City), 1977, Source Testing for Fireplaces, Stoves, and Restaurant Grills in Vail, Colorado, report for the U.S. Department of Energy, 26 pp.

265. Perera, F.P. and Ahmed, A.K., 1978, Respirable Particles, Natural Resources Defense Council, Inc., N.Y.

266. Peters, J.A., DeAngelis, D.G. and Hughes, T.W., 1980, An Environmental Assessment of POM Emissions from Residential Wood-Fired Stoves and Fireplaces, in: Fifth International Symposium on Polynuclear Aromatic Hydrocarbons, 11 pp.

267. Peters, J.A., DeAngelis, D.G. and Hughes, T.W., 1981, An Environmental Assessment of POM Emissions From Residential Wood-Fired Stoves and Fireplaces, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

268. Peters, J.A., Hughes, T.W. and DeAngelis, D.G., 1981, Wood Combustion Emissions at Elevated Altitudes, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

269. Peters, J.A., Hughes, T.W. and DeAngelis, D.G., 1981, Wood Combustion Emissions at Elevated Altitudes, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 252-259.

270. Phillips, J.W., Duncan, J.R. and Barnard, B.L., 1981, Regulating Residential Biomass Activities: The Historical Approach and Current Considerations in the Tennessee Valley Region and Their Potential Effect on the Full Implementation of TVA's Proposed Wood Heater Program, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

271. Pott, P., Chirurigal Works, v. 5, p. 63, London, 1975.

272. Prakash, C.B. and Murray, F.E., 1972, Studies on Air Emissions from the Combustion of Wood-Waste: Combustion Science and Technology, v. 6, p. 81-88.

273. President Carter's April 5, 1979, energy address to the nation.

274. Pullen, D.R., 1981, Design Features and Test Experience of Domestic Wood Fired Heaters in New Zealand, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

275. Pullen, D.R. and Holden, R., Design Features and Test Experiences with Domestic Wood Fired Heaters in New Zealand, 15 pp.

276. Rawls, R.L., 1979, Dow Finds Support, Doubt for Dioxin Ideas: Chem. Eng. News 23.

277. Reddy, G.N., 1979, Characterization of Air Pollutant Emissions and Stack Parameters for Woodburning Sources, report for Argonne National Laboratories, 49 pp.

278. Reed, T.B., 1978, Developing a Biomass Energy Program for Seri & the Nation, in: Proceedings of Wood Heating Seminar 3, Madison, Wisconsin, p. 382-389.

279. Reiners, W.A., and Wright, H.E., Jr., 1977, Impact of Prehistoric and Present Fire Patterns on the Carbon Dioxide Content of the Atmosphere, in: Global Chemical Cycles and Their Alterations by Man, Stumm, W. (ed.), p. 121-135.

280. Report to the Oregon Department of Environmental Quality, 1979, on Projected Total Suspended Particulate Generated from Wood-Burning Stoves, 21 pp.

281. Roberts, C.F., 1973, Meteorological Problems in Smoke Management, in: Proceedings of International Symposium on Air Quality and Smoke From Urban and Forest Fires, Fort Collins, Colorado, published by National Academy of Sciences, Washington, D.C., 1976, p. 214-230.

282. Romero, A.E., Buchan, R.M. and Fox, D.G., 1978, A Study of Air Pollution From Fireplace Emissions at Vail Ski Resort: Journal of Environmental Health, v. 41, p. 117-119.

283. Rossman, D.R., and Odell, F.G., 1980, Evaluation of Wood Stove Emissions, report for Oregon Department of Environmental Quality and U.S. Environmental Protection Agency, 15 pp.

284. Rudling, L., Ahling, B. and Lofroth, G., 1980, Chemical and Biological Characterization of Emissions from Combustion of Wood and Wood-Chips in Small Furnaces and Stoves, National Swedish Environment Protection Board, Report No. SNV PM 1331, 79 pp.

285. Rudling, L., Ahling, B. and Lofroth, G., 1981, Chemical and Biological Characterization of Emissions From Combustion of Wood and Wood-Chips in Small Furnaces and Stoves, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A. (ed.), Portland, Oregon.

286. Sanborn, C.R., Heil, G.A., Poirot, R. and Blanchet, M.A., 1981, Impact of Residential Woodburning on Ambient Air Quality in a Small New England Village, in: 74th Annual Meeting of the Air Pollution Control Association, Philadelphia, Pennsylvania, 16 pp.

287. Sanborn, C.R., Poirot, R.L., Heil, G.A. and Blanchet, M.A., 1981, Preliminary Analysis of the Ambient Impacts of Residential Woodburning in Waterbury, Vermont, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 231-241.

288. Santodonato, J. and Bruce, R., 1981, Multimedia Human Exposure to Polycyclic Aromatic Hydrocarbons and Their Association With Cancer Risks, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

289. Schaefer, V.J., 1973, The Production of Optimum Particle Smokes in Forest Fires, in: Proceedings of International Symposium on Air Quality and Smoke From Urban and Forest Fires, Fort Collins, Colorado, published by National Academy of Sciences, Washington, D.C., 1976, p. 27-29.

290. Schmeltz, I. and Hoffman, D., 1977, Nitrogen-containing Compounds in Tobacco and Tobacco Smoke: Chem. Dev., v. 77, p. 295.

291. Schrenk, H.H., et. al, 1949, Air Pollution in Donora, Pennsylvania, Public Health Service Bulletin, No. 306, p. 74.

292. Schuetzle, D., Prater, T., Riley, T., Durisin, A. and Salmeen, I., 1980, Analysis of Nitrated Derivatives of PAH and Determination of their Contribution to Ames Assay Mutagenicity for Diesel Particulate Extracts, in: Fifth International Symposium on Polynuclear Aromatic Hydrocarbons, Columbus, Ohio.

293. Schwengels, P., Bohac, C. and Krickenberger, K., 1981, An Integrated Environmental Assessment of Biomass Energy Development in the Tennessee Valley, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 272.

294. Sears, L., (ed.), 1981, 5 Quads From Wood Fuels by 1990, in: Energy News, Portland General Electric, Portland, Oregon, v. 4, no. 2, p. 1.

295. Sears, L., (ed.), 1981, U.S. Wood Resource Underutilized, in: Energy News, Portland General Electric, Portland, Oregon, v. 4, no. 6, p. 1.

296. Seeley, L.E. and Keator, F.W., 1940, Wood-Burning Space Heaters: Mechanical Engineering, 62, p. 867-870.

297. Shafizadeh, F., 1981, The Chemistry of Pyrolysis and Combustion of Wood, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

298. Shelton, J., 1976, Wood as an Energy Resource: Woodburners Encyclopedia, Chapter 1, Vermont Crossroads Press, Waitsfield, Vermont.

299. Shelton, J., 1979, Wood Heat Safety, Garden Way Publishing Co., Charlotte, Vermont, p. 82-87.

300. Shelton, J., 1980, Air Pollution from Residential Woodburning Appliances, 19 pp.

301. Shelton, J., 1980, Creosote and Wood Moisture Content, in: Canadian Wood Energy Institute Annual Conference, Toronto.

302. Shelton, J.W., 1981, Results of the Research on Catalytic Combustion on Wood Stoves, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 278.

303. Shelton, J.W., 1981, Wood Heating System Design Conflicts and Possible Resolutions, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

304. Shelton, J., et al., 1978, Wood Stove Testing Methods and Some Preliminary Results, in: Transactions of the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), 48, p. 388-404.

305. Shelton, J. and Shapiro, A.B., 1976, The Woodburners Enclopedia, 155 pp.

306. Sherman, M.H., Grimsrud, D.T., Condon, P.E. and Smith, B.V., 1980, Air Infiltration Measurement Techniques, Lawrence Berkeley Laboratory, Report No. LBL-10705, 33 pp.

307. Short, W.T., 1974, Particulate Carbon Monoxide, and Hydrocarbon Emissions from Residential Fireplaces, Albuquerque Department of Environmental Health, Alburquerque, New Mexico.

308. Shorthill, J., 1977, Wood Stove Emissions: Major Stationary Sources and the Ambient Air Quality Mandated by the Clean Air Act of 1970; Idea: the Journal of Law and Technology, 19, p. 355-370.

309. Smith, J.R. and Suggs, J.C., 1973, in: Proceedings of International Symposium on Air Quality and Smoke From Urban and Forest Fires, Fort Collins, Colorado, published by National Academy of Sciences, Washington, D.C., 1976, p. 296-317.

310. Smith, K.R., Ramakrishna, J. and Menon, P., 1981, Air Pollution from the Combustion of Traditional Fuels: A Brief Survey, report for the Conference on Air Quality Management and Energy Policies, Baroda and Bombay, India, 56 pp.

311. Snowden, W.D., et al., 1975, Source Sampling Residential Fireplaces for Emission Factor Development, Prepared by Valentine, Fisher, and Tomlinson for U.S. Environmental Protection Agency, Report No. EPA-450/3-76-010, 173 pp.

312. Spengler, J.D., et al., 1979, Indoor-Outdoor Air Pollution Relationships: Results of the Indoor-Outdoor Monitoring Program of the Harvard Six City Study, in: Air Pollution Control Association 72nd Annual Meeting, Cincinnati.

313. Stegmeir, P.B., 1981, Wood Energy From the Forest to the Furnace, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

314. Stone, R.L., 1979, Solving the Creosote Problem with Controlled Chimney Temperature, in: Proceedings of Wood Heating Seminar 5, St. Louis, Missouri, p. 199-219.

315. Talbott, Wong and Associates, 1979, Changes in the Emission Rate of Total Suspended Particulate...as the Result of Wood Burning for Space Heating in the Portland/Vancouver Air Quality Maintenance Area: draft prepared for Oregon Department of Environmental Quality.

316. Thornton, M.M. and Malte, P.C., 1981, C bustion Rate of Model Wood Volatiles, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

317. Thulman, R.D., Introduction to Wood Burning, The Fireplace Institute, Chicago, 19 pp.

318. Tomalis, L., et. al, 1978, Evaluation of the Carcinogenicity of Chemicals: A Review of the Monograph Program of the International Agency for Research on Cancer (1971 to 1977): Environmental News.

319. Tong, E.Y., Hirata, A. and Niemann,, B.L., 1979, Regional Air Quality Assessment for the Tennessee Valley Authority, Task 2: Air Quality Assessment of Increased Wood Burning, Prepared by Teknekron, Inc. for Tennessee Valley Authority, Report No. RM-033-TVA-79.

320. Turk, A., Oti, L.K., Steinberg, E. and Bergstein, T., 1981, Assessing the Performance of Activated Carbon in the Indoor Environment, in: 74th Annual Meeting of the Air Pollution Control Association, Philadelphia, Pennsylvania, 14 pp.

321. University of Main, Department of Agricultural and Resource Economics, 1977, Use of Wood and Other Fuels for Home Heating in Bangor, Old Town and Milford, Report No. ARE 294, 17 pp.

322. U.S. Comptroller General, 1980, Indoor Air Pollution: An Emerging Health Problem, Report To The Congress of the United States, Report No. CED-80-111, 34 pp.

323. U.S. Department of Commerce, 1975, Statistical Abstracts of the United States, 1975, 1050 pp.

324. U.S. Department of Commerce, 1977, Airborne Particles, Publication No. Pb-276-723.

325. U.S. Department of Commerce, 1977, Current Housing Reports; Bureau of the Census Final Report H-150-75; Annual Housing Survey: 1975, Part A. General Housing Characteristics for the United States and Regions, 270 pp.

326. U.S. Department of Energy, Ovvice of Environment, 1979, Environmental Readiness Document: Wood Combustion, Report No. DOE/ERD-0026, 45 pp.

327. U.S. Environmental Protection Agency, 1973, Compilation of Air Pollutant Emission Factors, report AP-42, Second Edition.

328. U.S. Environmental Protection Agency, 1978, Compilation of Air Pollutant Emission Factors, NTIS Accession No. PB-275 525, Supplement NTIS Accession No. PB-288 908.

329. VanDewoestine, R.V., Zimar, F. and Allaire, R.A., 1981, Catalytic Combustion in Residential Wood Stoves, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 154-166.

330. Van Duuren, B.L., 1976, Tumor-Promoting and Co-Carcinogenic Agents in Chemical Carcinogenesis: Chemical Carcinogens, Searle, C.E., (ed.), American Chemical Society.

331. Vines, R.G., 1973, Characteristics and Behavior of Bushfire Smoke, in: Proceedings of International Symposium on Air Quality and Smoke From Urban and Forest Fires, Fort Collins, Colorado, published by National Academy of Sciences, Washington, D.C., 1976, p. 101-104.

332. Wainwright, P.B., 1981, Wood Energy - The North Carolina Effort, in: Proceedings of Wood Heating Seminar, New Orleans, Louisiana, p. 260-265.

333. White, E.W., 1978, Charcoal: Fuel for Thought: American Forest, 84.

334. Williams, J.R. and Justus, C.G., 1974, Evaluation of Nationwide Health Costs of Air Pollution and Cigarette Smoking: JAPCA, v. 24, p. 1063.

335. Wilson, A.T., 1978, Pioneer Agriculture Explosion and CO_2 Levels in the Atmosphere: Nature, v. 273, p. 40-41.

336. Winger, J.H., 1978, U.S. National Standards, in: Proceedings of Wood Heating Seminar 3, Madison, Wisconsin, p. 13-15.

337. Wong, C.S., 1978, Aymosphere Input of Carbon Dioxide from Burning Wood: Science, v. 200, p. 197-200.

338. World Health Organization, Geneva, 1961, Air Pollution Monograph Series.

339. Zimar, F. and Allaire, R., 1981, Catalytic Combustion in Residential Wood Heaters, in: Proceedings of International Conference on Residential Solid Fuels, Cooper, J.A., (ed.), Portland, Oregon.

Appendix 1
Residential Wood Combustion
Particulate Impact Assessment Method
Glossary

Chemical Mass Balance

This method matches source particle size and chemical "fingerprints" to those measured at the receptor to estimate the impact of specific sources. Given data on the ambient concentrations of several chemical species and the percent by weight of these species in the emissions from the sources, a set of equations is formed and solved to determine source impacts.

Carbon-14

"Modern" carbon sources, such as wood burning, can be distinguished from fossil fuel sources, based on the fact that the isotopic ratio of $^{14}C/^{12}C$ in plant tissue is in equilibrium with the same ratio in atmospheric CO_2, whereas fossil carbon contains essentially no ^{14}C because of its old age relative to the half life of the ^{14}C isotope (5730 years).

Light Scattering

Temporal variations in the light scattering characteristics of ambient air, as measured by an integrating nephelometer, can provide a measure of hourly and seasonal variability in fine particle mass concentrations which, when compared to diurnal and seasonal variations in residential wood combustion emissions, can provide a qualitative measure of likely impact.

Carbon Thermograph Analysis

Carbon thermographic techniques measure the concentration of carbon dioxide generation from stepwise combustion of the carbonaceous aerosol found in ambient air. Thermograms reflecting the relative amounts of carbonaceous material in the sample, as a function of combustion temperature, reflect distinct source profiles which, when compared to similar profiles developed for source emissions, can provide a qualitative indication of likely carbonaceous source impacts.

Dispersion Modeling

Urban dispersion models (CDMQC and Eulerian model) have been used to estimate residential wood combustion impacts given detailed information on atmospheric dispersion properties, a wood burning emission inventory and data describing the diurnal and seasonal variations in source strengths. In most studies, current residential wood combustion emission inventory data was developed through telephone surveys of each community studies.